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MUSKOKA LAKES WATER QUALITY EVALUATION

report number 3
eutrophication of the
muskoka lakes

may, 1973

Ministry
of the
Environment

Ontario

MUSKOKA LAKES

WATER QUALITY EVALUATION

Report Number 3

Eutrophication of the Muskoka Lakes

by

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Ministry of the Environment

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SUMMARY AND CONCLUSIONS

This third report of a series presents in chapter form the more technical and experimental aspects of a study dealing with the question of aquatic enrichment and the related problem of accelerated aging (eutrophication) in three lakes (Joseph, Rosseau and Muskoka) and four bays (Little Lake Joseph, Skeleton, Dudley and Gravenhurst) of the Muskoka Lakes system.

In general, excellent water quality prevailed throughout the study area except for Gravenhurst Bay where conditions of accelerated eutrophy were found. Classical indications of enrichment in the Bay included extremely low Secchi disc readings; oxygen depletions and high carbon dioxide, phosphorus, nitrogen, iron and silica in the lower waters; depressions of pH in the deeper strata; and higher chlorophyll a concentrations in the euphotic zone. Similar physical and chemical findings were not encountered elsewhere in the system. The advanced state of enrichment of Gravenhurst Bay was further substantiated by significant differences in phytoplankton, zooplankton and bottom fauna communities. For example, high levels of phytoplankton dominated by the blue-green "water-bloom" species *Anabaena* spp. and *Aphanizomenon flos-aquae* (L.) Ralfs reduced water-oriented recreational activities and diminished the aesthetic quality of the Bay during the late summer and early fall months. In addition, higher rates of primary production characterized Gravenhurst Bay compared with the rest of the study area.

A series of experiments carried out in large polyethylene bags suspended in Lake Joseph and Gravenhurst Bay to assess the relative importance of the three most significant nutrients (carbon, phosphorus and nitrogen) indicated that additions of these nutrients -either alone or in combination stimulated phytoplankton growth. However, highest biomass materialized in tubes receiving phosphorus - either alone or in combination with nitrogen and carbon. It was suggested that nitrogen and carbon further increased algal densities once adequate phosphorus was supplied. In a second series

of experiments, lower phytoplankton responses were recorded in tubes receiving sewage wastes treated for phosphorus removal than bags treated with typical secondary sewage effluent to stimulate a phosphorus loading similar to that affecting Lake Erie. A final experiment conducted in Gravenhurst Bay suggested that mixing of nutrients from the hypolimnion into the over-lying well-illuminated epilimnetic waters may act to maintain and augment algal densities where elevated nutrient concentrations develop in deep waters subjected to high nutrient loadings. However, all experiments were limited in that each approach was designed from the point of view of adding nutrients to systems. The extent and rate to which eutrophication is reversible can most conclusively be demonstrated by "taking away" on a lake-scale degree an element essential to aquatic plant growth.

Nutrient budgets for phosphorus, nitrogen, silica and carbon were developed for the main lakes and bays under study. Nutrient inputs were calculated and categorized under 1) land drainage, 2) cottages, 3) resorts, 4) municipal wastes, 5) rainfall and 6) carry-over from upstream to downstream lakes. With respect to phosphorus inputs from cottage septic tank-tile field systems, evidence is presented which indicates that the sandy Precambrian soils are of minimal value as tile bed soils because their capacity to retain phosphorus is limited and a considerable proportion of the phosphorus may be held only temporarily, that is until percolating rain-water washes this nutrient through to base flows.

Absolute inputs of phosphorus to the three lakes and four bays studied are presented in Table 1 of the summary. As indicated, Lake Joseph received almost one-half of its loading from cottage and resort wastes; land drainage contributed only 30%. Twenty percent of the total phosphorus loading to Lake Rosseau resulted from cottages and resorts while a similar contribution to Lake Muskoka resulted from municipal sources and only 6% from shoreline cottages and resorts. Land drainage inputs to Lakes Rosseau and Muskoka were substantial owing to their large watersheds. Gravenhurst Bay was heavily loaded with nutrients from municipal wastes; about 90% of the phosphorus and 70% of the nitrogen originated in municipal wastes. In comparison, cottage inputs to Gravenhurst Bay were low.

Table 1: Absolute inputs of phosphorus from land, municipal, recreational and rainfall sources to Lakes Joseph, Rosseau and Muskoka and to the four selected bays in the watershed, 1969.

Source	LAKES						BAYS							
	Joseph		Rosseau		Muskoka		Gravenhurst		Dudley		Skeleton		Little Joseph	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Land drainage	1,133	29.9	4,807	53.8	65,698	68.7	340	3.5	395	57.3	1,603	95.3	329	67.1
Cottage input	1,664	43.9	1,736	19.4	5,400	5.6	338	3.5	234	34.0	51	3.0	121	24.7
Resort input	150	3.9	276	3.1	335	0.4	-	-	-	-	-	-	-	-
Municipal input	-	-	360	4.0	20,197	21.2	8,933	92.3	-	-	-	-	-	-
Rainfall	847	22.3	993	11.2	2,176	2.3	69	0.7	60	8.7	28	1.7	40	8.2
Main lake above	-	-	759	8.5	1,786	1.8	-	-		-	-	-	-	-
Total	3,794		8,931		95,592		9,680		669		1,682		490	

NOTE: kg x 2.2 = lb.

Considering "net-inputs" to the entire system (i.e. the amount of nutrient contained in that input in excess of the amount of nutrient displaced in an equivalent volume of water), land drainage contributes almost one-half of the net input of phosphorus, but none of the net input of nitrogen. Cottages and resorts contributed about 15% of the net input of phosphorus and about 26% of the net input of nitrogen. Municipalities contributed significantly as they added 31% and 56% of net phosphorus and nitrogen loadings, respectively. The "net-input" concept is discussed in terms of affording a more realistic means of appraising the relative importance of various nutrient sources.

Phosphorus loading rates to each lake and bay were calculated according to Vollenweider's method. The decidedly eutrophic nature of Gravenhurst Bay was illustrated. Concern is expressed relative to the current "near-dangerous" status of Muskoka Lake. With respect to this lake,for the first time on record, a short-lived blue-green algal bloom materialized in October of 1971 over the entire surface of the lake - an initial indication of the somewhat tenuous nature of present day water quality.

The use of Vollenweider's (in press) model is discussed in terms of establishing the relative state of enrichment for the three lakes and four bays studied in predicting "trophic-status" changes associated with alterations in phosphorus loadings (for example, at Gravenhurst where phosphorus removal was effected at the Gravenhurst and Ontario Hospital Sewage Treatment Plants during the summer of 1971) and in estimating a lake's population density or cottage capacity in relation to desired water quality. In this regard, correlations were developed between 1) phosphorus loadings and mean summer Secchi disc values, 2) phosphorus loadings and mean summer chlorophyll a concentrations and 3) phosphorus loadings and mean standing stocks of algae; predictions are advanced relative to responses which would materialize to these key eutrophication parameters with increasing populations. The data are used to illustrate that technical refinements to municipal and cottage waste treatment systems would guarantee water quality in Precambrian recreational lakes.

RECOMMENDATIONS

1. Physical, chemical and biological investigations should continue in Gravenhurst Bay to establish the extent and rate of restoring water quality as a consequence of efforts to reduce in excess of 80% of the phosphorus loadings from the Gravenhurst and Ontario Hospital Sewage Treatment Plants to the Bay.

    Personnel of the Biology Section, Water Quality Branch will continue with limnological studies on Gravenhurst Bay to assess the effectiveness of phosphorus removal as a means of reversing the process of eutrophication.

2. Phosphorus removal from all municipal and resort discharges throughout the Muskoka Lakes and upstream waters would significantly reduce the "net-loading" and would safeguard the predominantly good water quality that characterizes most of the system.

    By 1975, the Government of Ontario expects to have controls in operation at more than 200 municipal waste water treatment plants across the Province serving some 4.7 million persons. This represents about 90% of the population serviced with sewers. The programme is in response to the International Joint Commission recommendation as embodied in the U.S. - Canada Great Lakes Water Quality agreement and has been expanded by staff of the Ministry of the Environment to include inland recreational waters which show phosphorus to be a major factor in influencing eutrophication.

3. Studies should be conducted to establish whether existing specifications for septic tank-tile field systems installed where coarse-textured light soils overlay impervious bedrock are effective in preventing bacterial and nutrient contamination of surface waters. Additionally, alternative

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FURTHER INFORMATION

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and/or modifications to existing cottage waste treatment procedures should be evaluated for sites where conventional septic tank installations would not be expected to protect water quality.

Personnel of the Ministry's Private Waste and Water Management Branch are currently assessing the degree and rate of seepage from septic tank-tile field systems using radio-active tracers in order to establish closer relationships between varying on-site conditions, soil types and bacterial and nutrient containment. Additionally, a study to evaluate various factors associated with holding tank pump-out facilities (i.e. tank design, metering, pumping system and disposal techniques) is currently under commission to the Private Waste and Water Management Branch. Scientists and engineers of the Ministry are considering a number of pilot and lake-scale studies which would determine the effectiveness of various septic tank and/or tile bed additives as phosphorus complexing reagents.

4. The use of phosphate-free washing compounds is highly recommended. In past years, approximately 50% of the phosphorus contributed by human sewage was added by detergents. Cottagers having any doubt about the possibility of nutrients reaching the lake from their treatment systems should refrain from installing automatic dishwashers which require high phosphate cleaning products (a 1970 questionnaire indicated that 30% of the cottages in the Muskoka Lakes have automatic dishwashers). Such conveniences may contribute significant amounts of phosphorus to recreational lakes. In most of Ontario's vacation land, lake water used by cottagers is sufficiently soft to allow for the exclusive use of soaps and soap flakes.

On August 1, 1970, federal regulations reduced the phosphorus content as P_2O_5 in laundry detergents from approximately 50% to 20%. Additional regulations which were effected on January 1, 1973, further decreased the phosphate content to 5%.

5. A significant number of cottage owners apply lawn and garden fertilizers each year to promote vigorous growth. Use of fertilizers in shoreline areas should be limited as much as possible and discontinued if translocation to the lake is deemed likely.

   Unless cottagers endeavour to understand the causes and consequences of artificial nutrient enrichment and eliminate offending practices and inadequate treatment systems, water quality is certain to be undermined for future generations.

INTRODUCTION

"We have met the enemy and he is us." - Pogo

Over the past few years numerous complaints concerning troublesome levels of algae in Muskoka Lake (Gravenhurst Bay in particular) as well as in a number of other recreational lakes of Precambrian origin including Little Lake Panache (near Sudbury), Riley Lake (southeast of Gravenhurst), Silver Lake (near Port Carling) and Big Straggle Lake (near Bancroft) led to a thorough multi-disciplinary water quality evaluation of Lakes Joseph, Rosseau and Muskoka. The overall objective of the three-year investigation was to assess the status of nutrient enrichment and to determine the rapidity with which changes are occurring in order to promote the implimentation of protective measures before the existing good water quality which characterizes most of the system is undermined. Although the most intensive aspects of the study were carried out in 1969 and 1970, ongoing experimental efforts are presently in progress in Gravenhurst Bay. It should be recognized that the findings and recommendations of this study are applicable to many soft-water lakes in the Precambrian Shield region of Ontario as the Muskoka area is generally representative of geological and topographical conditions throughout a large portion of the province's vacation and wilderness area.

This third report of a series (previous publications include Michalski and Robinson 1971 and Boelens and Rumsey 1972) presents in chapter form the more technical and experimental aspects of the study dealing with the question of aquatic enrichment and the related problem of accelerated aging (eutrophication) of the Muskoka Lakes system. Included are chapters relating to the physical-chemical limnology of the system, information on phytoplanktonic, zooplanktonic and bottom faunal populations throughout the study area, and the ingress and egress of major plant nutrients. Also, the results of a series of experiments to determine nutrients limiting to algal growth are presented. It is anticipated that the data presented will be useful as "benchmarks" against which future water quality conditions can be measured.

CHAPTER 1

PHYSICAL-CHEMICAL LIMNOLOGY

CHAPTER 1 - PHYSICAL-CHEMICAL LIMNOLOGY

INTRODUCTION

This chapter summarizes information of a physical-chemical nature for three lakes (Joseph, Rosseau and Muskoka) and four bays (Little Lake Joseph and Skeleton, Dudley and Gravenhurst Bays) studied during 1969 and 1970. The data are important in interpretation of biological conditions throughout the system and for use as base-line information for future comparisons of water quality.

DESCRIPTION OF THE STUDY AREA

The three Muskoka Lakes - Lake Muskoka, Lake Rosseau and Lake Joseph - are situated in the Canadian Precambrian Shield approximately 150 kilometers (90 miles) north of Lake Ontario and 20 kilometers (12 miles) east of Georgian Bay of Lake Huron. The watershed (at Bala) of 4,610 square kilometers (1,779 square miles) consists of lakes, outwash sands and outcroppings or igneous metamorphic rock. The lakes are relatively large and deep and have many islands and high shoreline development. Bays are often semi-enclosed and some degree of basin individuality is evident in each. In addition to four main lake stations examined, four bays were included in the study (Figure 1.1) in order to evaluate possible differences in water quality associated with varying densities of shoreline development. Morphometric values and population figures for the selected lakes and bays are indicated in Table 1.1. Lake Muskoka is the most populated and Lake Joseph is the least and most recently developed of the three lakes, with Lake Rosseau occupying a middle position. Gravenhurst Bay (M-1) and Dudley Bay (M-4) are the most heavily populated of the bay situations and have been so for the longest time; Skeleton Bay (R-5) of Lake Rosseau and Little Lake Joseph (J-8) of Lake Joseph are the least intensively developed and have attracted growth more recently.

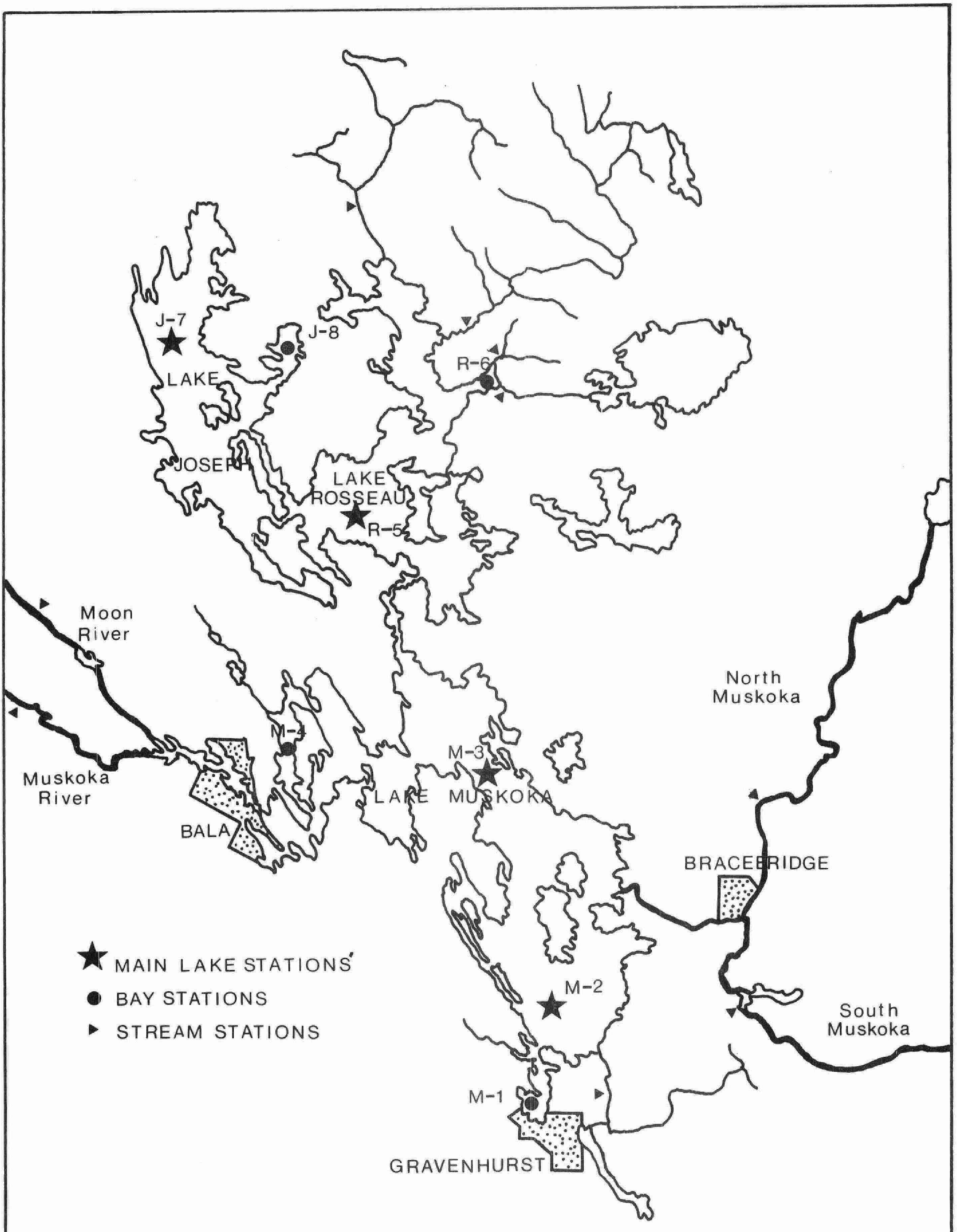

Figure 1.1: Diagrammatic representation of the Muskoka Lakes study area. Main lakes and bays as well as tributaries sampled are presented.

Table 1.1: Morphometry of the three lakes and four bays selected for study. Data are presented in metric and British units.

	Watershed Area km^2 mi^2	Lake Area km^2 mi^2	Lake Volume $m^3 \times 10^9$ $ft^3 \times 10^9$	Mean Depth m ft	Maximum Depth m ft	Population (Man Years) Cottage and Hotel	Municipal
LAKES							
Joseph	126.7 48.9	49.9 19.2	1.255 44.847	25.3 83.3	93.8 308.0	1.08×10^3	-
Rosseau	774.8[a] 299.2	58.5 22.5	1.481 52.911	25.5 83.9	90.2 296.0	1.69×10^3	0.23×10^3
Muskoka	4,610.1[b] 1,779.9	49.5 19.1	2.131 76.126	16.8 55.2	67.0 220.0	4.53×10^3	13.46×10^3
BAYS							
Little Lake Joseph	36.9 14.2	2.3 0.8	1.423 0.039	17.0 56.0	38.7 127.0	0.81×10^2	-
Skeleton	206.6 79.7	1.6 0.6	0.015 0.559	9.4 31.0	20.1 66.0	0.45×10^2	-
Dudley	43.3 16.7	3.5 1.4	0.024 0.861	6.7 22.0	18.2 60.0	2.1×10^2	-
Gravenhurst	37.3 14.4	4.0 1.5	0.028 1.026	7.0 23.0	15.8 52.0	3.0×10^2	59.0×10^2

[a] = includes watersheds of Joseph and Rosseau Lakes taken at Port Carling

[b] = includes watersheds of Joseph, Rosseau and Muskoka Lakes taken at Bala.

Larger municipalities such as Gravenhurst and Bracebridge have water pollution control plants serving most of their residents, although portions of these municipalities are serviced by septic tank-tile field disposal systems. For example, domestic wastes for only two-thirds (i.e. 2,200 people) of the urban area of Gravenhurst are treated in a conventional activated sludge treatment plant with a rated hydraulic capacity of 450,000 G.P.D. in dry weather flow. The plant has been designed to accommodate wastes from 4,000 persons with an organic loading of 652 pounds of B.O.D. per day. Approximately 90% B.O.D. and suspended solids reduction are attained at this municipal plant. In addition, domestic wastes from the Ontario Hospital and the Ontario Fire College on Gravenhurst Bay are directed to an extended aeration sewage treatment plant with a rated hydraulic capacity of 70,000 gallons per day having an organic loading capacity of 226 pounds B.O.D. per day. Full scale phosphorus removal operations were initiated during July 1971 at the municipal sewage plant and during September 1971 at the Ontario Hospital sewage treatment system. In excess of 80% phosphorus removal is currently being effected at both locations. Most of the larger lakeside hotels utilize oxidation ponds as a method of waste treatment. These lagoons are either total retention or are drained once or twice per year.

METHODS

Meteorological

General

Data on precipitation and air temperature (^{0}C) were obtained using records supplied by the Federal Department of Transport Station located at Milford Bay on Lake Muskoka.

Incident light

Continuous solar radiation was measured by connecting a Weston photovoltaic weatherproofed cell (Model 856; Type "YR") to a Rustrak A.C. Recorder.

The cell was mounted on the roof of a Mobile Laboratory at Port Carling and located to ensure that interference from local shadows would be minimal. Photosynthetically active light for each day was obtained from the chart by computing the total area under the curve (by planimetry) and converting to langleys (1 langley = 1 g cal cm^{-2}). The latter conversion was accomplished using data for clear days from the National Research Council at Ottawa, a location approximately the same latitude as Port Carling.

Physical properties of lake waters

Temperature

Vertical water temperatures were recorded at the eight sampling locations employing a telethermometer (Model FT3 Hydrographic Thermometer). The instrument was calibrated at least weekly against a standard laboratory thermometer (accuracy ± 0.5 ^{o}C). Temperature readings were taken at each meter of depth on each visit to a station, although fewer readings sufficed when homothermal or near-homothermal conditions existed.

Light transmission

Penetration of light was determined at each sampling date with a Secchi disc (30cm) and a Gemware submarine photometer.

Water chemistry

Dissolved oxygen profiles were established at each of the sampling sites using the Winkler method. All water collections were taken with a 4 litre Van Dorn sampler. Additions of manganese sulphate, alkalide azide and sulphuric acid reagents and titrationswith sodium thiosulphate were carried out in the field. Generally, oxygen concentrations were determined from one point-source epilimnion sample (1.0m) and one hypolimnion sample (2.0m above bottom). However, under conditions of thermal stratification up to 12 depths were sampled; particular attention was devoted to establishing the oxygen regime in the vicinity of the thermocline.

Samples for pH, free CO_2, alkalinity and conductivity were collected from a depth of 1m and at 2m above bottom in 250ml gas bottles and were held in a portable cooler for transit to the field laboratory. The pH of a 100ml aliquot was measured using a Portomatic pH meter (Model 175 - Instrumentation Laboratories Inc.). As pointed out by Conroy (1971), pH is extremely difficult to measure in Precambrian lakes since even small additions of ions from the electrode may induce changes in the inherent ion activity. However, continuous stirring assisted in the provision of consistent results. A 100ml aliquot was titrated with fresh 0.02N NaOH until a pH of 8.3 was reached to determine the concentration of free CO_2 (mg l^{-1} CO_2). To obtain a total alkalinity (mg l^{-1} $CaCO_3$), a second sub-sample was titrated with 0.02N H_2SO_4 to a pH end-point of 4.3. Conductivity was determined on residual water using an Electronic Switch Gear - Model MC-1 Mark V meter. Final recordings were temperature adjusted to 25°C and expressed as μmhos cm^{-3}.

Chemical and chlorophyll samples were collected as composites representing the euphotic zone. Additionally, chemical samples were secured from 2m off bottom. The euphotic zone samples were obtained by alternately lowering and raising 1,000ml bottles provided with restricted inlets to the approximate location of the 1% incident light level (determined as twice the Secchi value), while the single point-source hypolimnion sample was taken with a Van Dorn sampler. Each chemical sample was subdivided into two 500ml acid-washed (1% HCl solution) plastic bottles, one 175ml sterile bottle and one 1,000ml bottle. One plastic bottle was frozen for phosphorus and nitrogen analyses while the second plastic container was refrigerated for silica, manganese and iron determinations. The 175ml sub-sample was maintained at 8°C and submitted for inorganic and total carbon analyses. The chlorophyll samples were preserved with 1ml of a 2% suspension of magnesium carbonate; 300-1,000 mls of this sample were filtered under vacuum pressure in the Mobile Laboratory using a 1.20 μ millipore filter, followed by cold storage in plastic containers until shipment to Toronto.

The nutrient and chlorophyll samples were transported to the Ministry of Environment's Division of Laboratories in Toronto for analyses. Nutrient determinations were performed on each water sample collected for total phosphorus (as P), total Kjeldahl, free ammonia and nitrate nitrogen (as N) and orthosilicate (molybdate reactive portion of soluble silica expressed as SiO_2).

Also, determinations for iron (as Fe), manganese (as Mn) and inorganic carbon (as C) were completed. All analyses were standard techniques utilized by the Chemistry Branches of the Ministry. Chlorophyll determinations were completed following the method of Brydges (1971a).

RESULTS

Meteorological conditions

Some meteorological data for the Muskoka area are presented in Tables 1a and 1b of Appendix 'A'. Mean monthly temperatures for the two study years ranged between a minimum of -20.4°C and a maximum of 25.7°C. Temperatures were as low as -36.1°C (January and February 1970) while a summertime maximum of 31.6°C was recorded in July 1969.

Total annual precipitation and snow fall values for 1969 were 90.0 and 221.1cm respectively; corresponding values for 1970 were 101.9 and 316.9cm, respectively.

Continuous solar radiation (g cal cm^{-2}) computed from our Weston photocell - Rustrak recorder for the six month field portions of the study indicates that highest quantities of light energy occurred during July of 1969 and in June of 1970. Extrapolation of the six month data for each of the years to total yearly solar radiation (using figures reported from the NRC Research Meteorological Station in Ottawa) yielded values approximating 115,680 and 114,550 g cal cm^{-2} $year^{-1}$ for 1969 and 1970, respectively.

Light and temperature

Transparencies were usually greater in the larger lakes than in the isolated bays as determined with a submarine photometer (Figures 1 to 8 of Appendix 'A') and Secchi disc (Table 1.2). The deepest compensation point (1% incident light level) of 26.5m occurred on August 5, 1969 in Lake Joseph;

Table 1.2: Extreme and mean Secchi disc values (m) for the eight sampling locations, 1969 and 1970.

Location	1969			1970		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Lakes						
Joseph	5.9	13.2	8.1	6.0	10.0	8.2
Rosseau	4.8	8.0	6.0	5.2	7.6	6.3
Muskoka (M-2)	2.9	6.4	4.3	3.8	5.0	4.5
Muskoka (M-3)	2.6	6.0	4.2	3.2	5.1	4.6
Bays						
Little Lake Joseph	3.6	7.4	5.8	4.7	8.0	6.3
Skeleton	4.0	7.5	5.0	4.3	6.0	5.3
Dudley	3.0	6.0	4.9	3.8	6.0	5.1
Gravenhurst	1.5	4.9	2.6	1.0	5.0	2.8

in contrast, a euphotic zone of only 3.0m was measured on May 20, 1969 at M-1 in Gravenhurst Bay. At this latter location, photometer measurements showed low transparencies in May of both years, with light penetration progressively increasing throughout the summer (Figure 1 of Appendix 'A'). In the fall the compensation point was 2-3 times early spring values. These euphotic-zone extensions were not as evident at other locations as at M-1.

Well-defined thermoclines developed at all eight sampling locations. The times of formation and description and the position of the thermoclines are indicated in Figures 1-8 of Appendix 'A'. The euphotic zone was situated above the thermocline at the four Muskoka Lake stations but extended well into the hypolimnion at J-7 and J-8. In Lake Rosseau and Skeleton Bay the 1% incident light level approximated the lower limit of the thermocline. A downward movement of the thermocline in the late summer and fall was observed at all sampling sites, although depressions were generally more pronounced in the bays than at the open-water sites.

Dissolved oxygen

Isopleths of dissolved oxygen for each of the eight sampling locations are provided in Figures 9 to 16 of Appendix 'A'. The main lake stations (M-2, M-3, R-5 and J-7) were well supplied with oxygen at all depths as indicated by the mid-summer orthograde distribution patterns (Figures 10, 11, 13 and 15, respectively). Anaerobic or near-anaerobic conditions developed in the hypolimnia of Gravenhurst, Dudley, Skeleton and Little Joseph Bays (Figures 9, 12, 14 and 16, respectively). The oxygen deficit was particularly extreme in Gravenhurst Bay; for example, as early as July 15, 1969 concentrations below 4m were 4.0 mg l^{-1} or less. Although a clinograde distribution normally characterized the waters of Gravenhurst Bay (Figure 9), occasionally a negative heterograde curve with a distinct oxygen minimum in the mid-thermocline region was detected. At a number of other stations, metalimnetic or hypolimnetic oxygen maxima in excess of those expected from temperature changes alone were detected (for example, see Figures 10 and 16 of Appendix 'A').

Rates of oxygen depletion computed for samples taken 2m above bottom for the eight locations in 1969 are illustrated in Figure 1.2 while other deep-water temperature and oxygen characteristics are summarized in Table 1.3. Although a complete oxygen loss did not occur at 2m above bottom at M-1, anaerobic conditions were apparent at 20cm above bottom commencing during the mid-summer of both years. As expected, the rate of oxygen depletion was highest for Gravenhurst Bay and lowest for Lake Joseph. Intermediate rates were recorded for Skeleton and Dudley Bays. The theoretical saturation concentration at the time of the spring overturn usually was slightly higher than a back-calculated concentration, indicating that a slight oxygen deficit existed in sub-surface waters at the onset of the growing season.

Mean oxygen concentrations in the hypolimnia followed the same critical pattern as that observed for oxygen deficit rates and concentrations at 2m above bottom (Table 1.3 and Figure 13 of Appendix 'A').

Ionic properties and free CO_2

Concentrations of the major ions in the surface waters are summarized in Table 1.4. As indicated, sulphate, calcium and bicarbonate were higher than magnesium, sodium, potassium and chloride. Table 1.5 summarizes pH, alkalinity, free CO_2 and conductivity data at 1m of depth and at 2m above bottom for each of the eight sampling locations. As expected, Gravenhurst Bay was characterized by extreme values of the aforementioned parameters. Considering the entire study area, pH values were higher in the surface than in the deeper strata. Alkalinity and conductivity concentrations were generally uniform with depth. Free CO_2 concentrations were barely detectable in the surface waters, especially during the mid-summer. The vertical distribution of free CO_2 followed an inverse relationship to dissolved oxygen as hypolimnetic values were 1.5 - 30 times surface-water concentrations.

Nutrient considerations

The seasonal patterns for total phosphorus, nitrate, free ammonia and total organic nitrogen and silica in the euphotic zone and at 2m above bottom for 1969 are presented in Figures 17 - 21 of Appendix 'A', respectively.

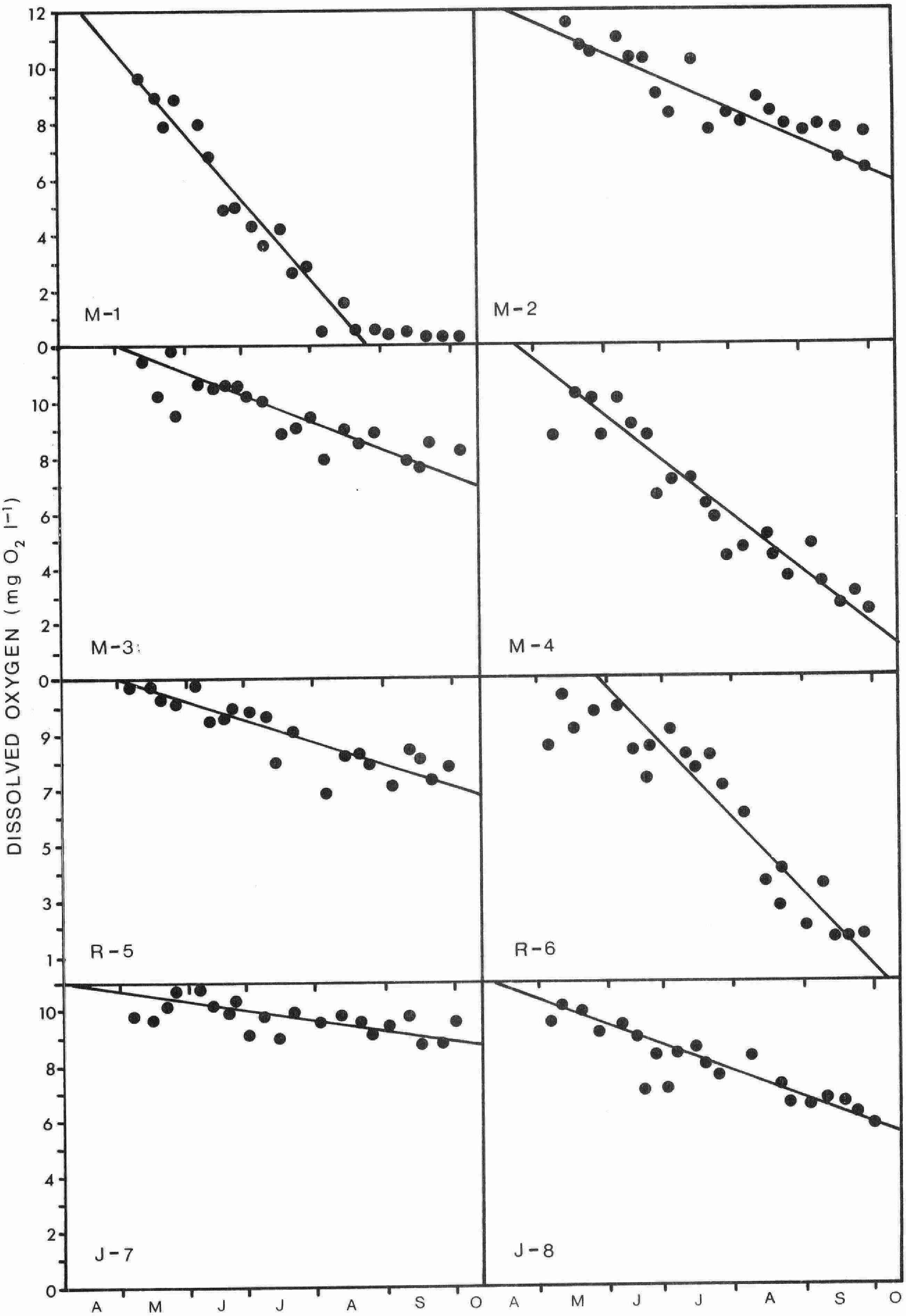

Figure 1.2: Oxygen conditions at 2m above bottom at each sampling location during the ice-free season of 1969. Rates of oxygen depletion computed from these figures are presented in Table 1.3.

Table 1.3: Temperature and oxygen characteristics in the near-bottom waters and in the hypolimnia for the eight sampling sites, 1969.

Sampling Site	Depth at Station (m)	Mean temperature-2m above bottom (^{o}C)	Minimum dissolved oxygen-2m above bottom (mg l^{-1})	Rate of oxygen depletion-2m above bottom (mg l^{-1} day $^{-1}$)	Development of anaerobic conditions at 20cm above bottom [a]	Mean oxygen concentrations in hypolimnia (mg l^{-1})
Lakes						
Joseph	67.6	5.0 ± 0.4	8.6	0.011	No	9.7
Rosseau	49.0	5.4 ± 0.3	6.8	0.024	No	9.3
Muskoka (M-2)	48.2	5.9 ± 0.3	6.5	0.032	No	9.1
Muskoka (M-3)	54.0	6.0 ± 0.4	7.3	0.027	No	9.5
Bays						
Little Lake Joseph	38.0	4.3 ± 0.3	5.8	0.021	No	8.2
Skeleton	21.8	6.7 ± 0.5	2.5	0.069	No	6.8
Dudley	18.2	8.0 ± 0.4	1.7	0.058	No	6.5
Gravenhurst	15.8	7.6 ± 0.3	0.2	0.091	Yes	1.9

a = Aliquots taken each week from a core sampler.

Table 1.4: Concentrations of major ions in the surface waters of the Muskoka Lakes (meq l^{-1}). All values except HCO_3^- are means of samples collected during the summer of 1969. HCO_3^- values represent a mean of at least 34 samples for each location.

Stations	Ca^{++}	Mg^{++}	Na^+	K^+	Total	HCO_3^-	Cl^-	$SO_4^=$	Total
Lakes									
Joseph	0.2	0.167	0.165	0.027	0.559	0.250	0.008	0.270	0.528
Rosseau	0.2	0.167	0.065	0.021	0.453	0.200	0.006	0.239	0.445
Muskoka (M-2)	0.2	0.167	0.061	0.015	0.443	0.216	0.008	0.239	0.463
Muskoka (M-3)	0.2	0.167	0.065	0.015	0.447	0.208	0.008	0.250	0.466
Bays									
Little Lake Joseph	0.2	0.167	0.070	0.018	0.455	0.210	0.006	0.239	0.455
Skeleton	0.2	0.167	0.061	0.015	0.443	0.244	0.006	0.239	0.489
Dudley	0.2	0.167	0.065	0.021	0.453	0.225	0.008	0.239	0.472
Gravenhurst	0.3	0.250	0.052	0.023	0.615	0.408	0.014	0.239	0.661

Table 1.5: Mean and extreme values for pH, alkalinity (mg $CaCO_3$ l^{-1}), free CO_2 (mg l^{-1}) and conductivity (μmhos cm^{-3} at 25°C) at 1m and 2m above bottom at eight sampling locations in the Muskoka Lakes, 1969-1970.

Stations	Depth (m)	pH		Alkalinity		Free CO_2		Conductivity	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Lakes									
Joseph	1.0	6.5	5.2 - 8.0	11.3	5.0 - 24.5	2.4	1.0 - 4.4	48.1	29.8 - 67.7
	65.6	5.8	5.2 - 7.7	10.5	5.0 - 27.5	5.0	1.5 - 8.9	46.2	30.0 - 62.9
Rosseau	1.0	6.5	5.1 - 7.0	15.2	5.0 - 32.0	2.8	0.5 - 7.4	44.9	30.3 - 68.7
	47.0	6.1	5.2 - 7.5	14.3	5.0 - 22.5	7.2	1.5 - 16.5	47.6	29.0 - 61.6
Muskoka (M-2)	1.0	6.6	5.3 - 7.9	17.5	5.0 - 25.0	2.5	1.0 - 4.2	46.9	33.5 - 63.7
	46.2	6.2	5.4 - 7.3	16.3	7.5 - 26.8	7.4	2.5 - 20.0	47.9	33.8 - 67.2
Muskoka (M-3)	1.0	6.5	5.6 - 7.2	15.5	5.0 - 24.0	2.7	1.4 - 6.3	49.2	32.9 - 78.0
	52.0	6.2	5.6 - 7.7	16.8	5.0 - 26.0	5.5	2.0 - 18.0	47.7	32.2 - 62.1
Bays									
Little Lake Joseph	1.0	6.9	6.0 - 7.8	11.4	5.0 - 27.0	2.8	1.4 - 6.2	47.3	29.9 - 75.2
	36.0	6.3	5.2 - 6.8	11.5	5.0 - 22.0	9.9	3.4 - 22.7	47.8	30.6 - 64.4
Skeleton	1.0	6.4	5.2 - 7.5	14.0	5.0 - 28.2	2.8	0.5 - 7.0	49.0	29.2 - 82.6
	19.8	5.9	5.2 - 7.3	15.1	5.0 - 24.5	9.7	1.5 - 27.0	46.2	38.7 - 70.2
Dudley	1.0	6.4	5.5 - 7.1	15.9	10.0 - 25.0	2.6	1.0 - 5.1	49.6	32.1 - 65.7
	16.2	5.9	5.2 - 7.2	16.3	10.0 - 26.0	9.9	1.5 - 30.8	48.5	32.5 - 71.0
Gravenhurst	1.0	6.9	4.2 - 8.6	24.0	10.0 - 39.8	2.9	0.0 - 9.0	59.0	44.0 - 88.8
	13.8	6.2	5.5 - 7.1	26.4	16.8 - 39.8	13.5	2.0 - 38.6	63.2	44.3 - 99.1

Extreme and mean values for these data are summarized for both years in Table 1.6. Additionally, surface water inorganic carbon (expressed as the sum of carbon in free CO_2, HCO_3^- and $CO_3^=$), iron and chlorophyll a levels are presented in Table 1.6.

As indicated, total phosphorus levels in the euphotic zone were high during the early spring and early autumn months at all sampling sites. Significantly, Gravenhurst Bay surface water concentrations were 5 - 10 times higher than values recorded elsewhere in the study area. At 2m above bottom, definite accumulations were apparent during the mid-summer months at Stations M-1, M-4 and R-6 only.

Mid-summer euphotic zone nitrate-nitrogen depletions and hypolimnetic accumulations characterized all locations. In Gravenhurst Bay, surface nitrate levels were barely detectable between the middle of May and the end of September for both years. At the remaining locations, the epilimnion contained substantial nitrate concentrations. In Gravenhurst Bay the deep-water nitrate levels diminished as soon as anaerobic conditions developed. Ammonia levels for surface and deep-waters reached a seasonal high during the last two weeks in June throughout the study area. Clearly defined hypolimnetic ammonia accumulations were noted only in Gravenhurst Bay during the late summer and early fall months. Euphotic zone and deep water organic nitrogen concentrations were extremely variable from week to week.

Silica levels were almost without exception, higher in the bottom waters than in the upper strata. Epilimnetic concentrations were usually highest in the early spring and late fall. In Gravenhurst Bay, late spring and early fall surface-water concentrations for this nutrient were barely detectable.

Inorganic carbon concentrations were extremely low throughout the system; in fact, levels are amongst the lowest recorded in the literature (see Johnson et al. 1970, Johnson and Michalski 1970, Schindler and Nighswander 1971, Armstrong and Schindler 1971, Schindler and Holmgren 1971 and Schindler et al. 1971 for other inorganic carbon data for Precambrian lakes).

Table 1.6: Extreme and mean concentration of total phosphorus ($\mu g\ l^{-1}$ as P), nitrate, free ammonia and total organic nitrogen ($\mu g\ l^{-1}$ as N), inorganic carbon (mg l^{-1} as free $CO_2 + HCO_3^- + CO_3^=$), total iron (mg l^{-1} as Fe), orthosilicate (mg l^{-1} as SiO_2) and chlorophyll a ($\mu g\ l^{-1}$) in the euphotic zone and at 2m above bottom at eight sampling locations in the Muskoka Lakes, 1969-1970.

Stations	Depth (m)	Total Phosphorus Mean	Total Phosphorus Range	Nitrate Nitrogen Mean	Nitrate Nitrogen Range	Free Ammonia Mean	Free Ammonia Range	Total Organic Nitrogen Mean	Total Organic Nitrogen Range
Lakes									
Joseph	e.z.	8.2	1 - 18	75.5	20 - 140	21.6	10 - 60	187.1	70 - 370
	65.6	7.6	2 - 38	124.5	40 - 190	22.1	10 - 70	186.9	60 - 350
Rosseau	e.z.	7.7	1 - 19	106.1	30 - 180	24.3	10 - 80	223.6	40 - 470
	47.0	8.6	1 - 31	177.5	110 - 320	22.0	10 - 70	192.1	40 - 350
Muskoka (M-2)	e.z.	10.0	5 - 26	102.5	20 - 157	26.1	2 - 70	258.4	120 - 510
	46.2	9.2	2 - 42	184.0	110 - 340	23.3	3 - 63	205.7	80 - 360
Muskoka (M-3)	e.z.	9.4	3 - 18	112.0	30 - 220	24.7	10 - 50	236.4	70 - 430
	52.0	11.1	3 - 30	170.0	100 - 240	22.0	10 - 80	213.9	90 - 340
Bays									
Little Lake Joseph	e.z.	8.8	2 - 19	42.0	6 - 110	33.6	10 - 160	219.2	100 - 440
	36.0	6.3	2 - 12	124.5	20 - 198	20.1	10 - 130	182.1	60 - 360
Skeleton	e.z.	8.6	2 - 16	113.5	30 - 200	24.5	10 - 60	199.1	90 - 440
	19.8	11.0	3 - 27	193.5	110 - 350	27.2	10 - 60	203.3	60 - 370
Dudley	e.z.	8.0	2 - 19	106.0	30 - 170	25.6	10 - 60	240.0	130 - 390
	16.0	13.2	4 - 24	172.1	80 - 370	33.1	10 - 80	236.7	100 - 360
Gravenhurst	e.z.	39.8	15 - 80	36.6	1 - 220	32.1	0 - 120	398.0	170 - 778
	13.0	77.2	20 - 250	239.5	30 - 460	196.6	50 - 430	339.2	170 - 510

e.z = Euphotic zone sample

Table 1.6: Continued.....

Stations	Depth (m)	Inorganic Carbon Mean	Inorganic Carbon Range	Total Iron Range	Orthosilicate Mean	Orthosilicate Range	Chlorophyll a Mean	Chlorophyll a Range
Lakes								
Joseph	e.z.	0.84	0.21 - 1.56	0.0 - 0.06	0.66	0.0 - 1.1	1.07	0.3 - 2.3
	65.6	1.07	0.20 - 3.10	0.0 - 0.04	0.96	0.0 - 1.2		
Rosseau	e.z.	1.05	0.32 - 2.06	0.0 - 0.04	1.67	1.3 - 2.2	1.70	0.6 - 4.0
	47.0	1.05	0.19 - 1.57	0.0 - 0.05	2.25	1.9 - 2.7		
Muskoka (M-2)	e.z.	1.03	0.50 - 2.31	0.0 - 0.08	2.28	0.0 - 3.6	2.05	0.6 - 4.8
	46.2	1.24	0.12 - 1.56	0.0 - 0.08	3.52	0.0 - 4.3		
Muskoka (M-3)	e.z.	1.06	0.51 - 1.57	0.0 - 0.10	2.64	1.9 - 5.6	1.88	0.4 - 3.6
	52.0	1.20	1.09 - 1.73	0.0 - 0.10	3.56	1.8 - 6.4		
Bays								
Little Lake Joseph	e.z	0.88	0.50 - 1.50	0.0 - 0.04	0.78	0.4 - 1.5	2.48	0.4 - 5.8
	36.0	1.39	1.00 - 2.01	0.0 - 0.10	1.63	0.3 - 2.2		
Skeleton	e.z	1.27	0.50 - 3.62	0.0 - 0.06	2.07	1.4 - 5.7	1.48	0.3 - 3.8
	19.8	1.76	0.29 - 3.71	0.0 - 0.12	2.67	1.7 - 3.5		
Dudley	e.z.	1.13	0.43 - 2.67	0.0 - 0.06	2.59	1.8 - 4.2	1.49	0.2 - 3.6
	16.0	1.72	0.28 - 2.71	0.0 - 0.60	3.62	2.5 - 4.3		
Gravenhurst	e.z.	2.71	1.63 - 5.91	0.0 - 0.12	0.82	0.0 - 3.8	8.62	0.8 - 30.0
	13.0	5.62	0.72 - 8.10	0.0 - 1.02	2.08	0.0 - 3.6		

e.z = Euphotic zone

Usually, concentrations were slightly higher at 2m above bottom than in the euphotic zone with the exception of Gravenhurst Bay where substantially elevated deep-water values relative to surface concentrations were detected (see Table 1.6).

Total iron concentrations were extremely variable at all sampling locations. However, significant increases as high as 1.02 mg l^{-1} were apparent under anaerobic conditions in the bottom waters of Gravenhurst Bay.

Chlorophyll *a*

An indication of the seasonal pattern in chlorophyll *a* concentrations at the eight locations in 1969 is provided in Figure 22 of Appendix 'A' while the maximum, minimum and mean values for both years are summarized in Table 1.6. Plant pigment concentrations were very low at all sampling sites except for Gravenhurst Bay. Additionally, definite spring and fall maxima materialized throughout the study area. However, at M-1 a suggestion of a breakdown in this bimodal pattern of phytoplankton development was apparent, as relatively high concentrations characterized the surface waters during July. A maximum value of 30.0 μgm l^{-1} on October 29, 1969, at M-1 coincided with a "bloom" of blue-green algae.

DISCUSSION

Implications of light, oxygen, pH and chlorophyll

Although suspended and/or coloured material may influence water clarity, the primary factor contributing to differences in light penetration is usually related to densities of phytoplanktonic populations. Recent evidence gained from studies on lakes located in the Precambrian Shield suggests that lakes having Secchi disc readings less than 3m are eutrophic in nature while those exceeding 5m are oligotrophic in status. Lakes having Secchi disc recordings between 3 and 5m would be mesotrophic or moderately productive, that is, they have a moderate supply of nutrients, plant growths and biological production. On the basis of these guidelines alone Lakes Joseph, Little Joseph and Rosseau and Dudley Bay would be oligotrophic in nature while Gravenhurst Bay would be decidedly eutrophic. Lake Muskoka and Skeleton Bay would be mesotrophic in status.

In considering water quality, the Secchi disc data as well as information on the position of the euphotic zone relative to the thermocline warrant a comment. As indicated earlier, mean Secchi values ranged between 8.2m(Lake Joseph) and 2.6m (Gravenhurst Bay) and decreased in order from Lake Joseph to Lake Rosseau to Lake Muskoka (Table 1.2). Also, the compensation point at the four Muskoka stations was situated above the thermocline, while in Lake Rosseau and Skeleton Bay the euphotic zone approximated the lower limit of the thermocline,and extended well into the hypolimnia at Stations J-7 and J-8 (see Figures 1-8 of Appendix 'A'). These data indicate a progressive degradation in water clarity from Lake Joseph to Lake Rosseau to Lake Muskoka and relate largely to the fact that Lake Muskoka has been the most populated for the longest time while Lake Joseph has been the least and most recently developed.

The "lowering" of the thermocline which was particularly evident in the bay areas occurs naturally in many Precambrian lakes and results from a deepening of the epilimnion owing to periodic wind-induced vertical turbulence occurring throughout the summer months. This phenomenon may act to replenish nutrients (especially in Gravenhurst Bay) as dissolved minerals may be continuously incorporated in a lake's euphotic zone to support late summer and early fall phytoplankton stocks.

The deep-water oxygen deficits and corresponding clinograde oxygen distributions observed in 1969 and 1970 at M-1, M-4 and R-6 and, in 1969 at J-8 are related primarily to decomposition of the current year's production of algae following settling to the bottom. Additionally, oxidation of previous years' suspended and/or sedimented particulate matter may contribute to loss of oxygen in the deep water. Undoubtedly, both processes were responsible for the de-oxygenation noted in the deep waters of Gravenhurst, Dudley, Skeleton and Little Joseph Bays. The metalimnetic maxima detected (primarily at J-8) resulted from optimum photosynthesis in the mid-thermocline region. A number of authors including Eberly (1959, 1963 and 1964), Wetzel (1966), Findenegg (1963 and 1964) and Baker et al. (1969) have indicated that such dissolved oxygen distribution curves are characteristic of mesotrophic lakes. However, one must be extremely cautious when relating this type of distribution to a trophic condition as it is common to

many relatively, small, well-protected Precambrian lakes and usually occurs in combination with a shallow thermocline, a Secchi disc reading exceeding 5m and a nutrient-biomass-primary production regime characteristic of unpolluted oligotrophic lakes (Schindler and Nighswander 1970, Schindler 1971, Michalski and Robinson 1969, Michalski 1971 and Michalski and Conroy 1972). The negative heteorograde oxygen distribution detected in Gravenhurst Bay resulted from decomposition of settling organic material in the dense metalimnetic zone and reflects excessive production in the overlying euphotic area.

Oxygen deficits at 2m above bottom were slightly below the theoretical saturation at the time of the spring overturn suggesting incomplete estival and/or autumnal mixing or an accumulated demand from mid-winter settled organic debris. The extremely low mean hypolimnetic oxygen concentrations at M-1 preclude the use of Gravenhurst Bay for deep-water salmonid and coregonid species of fish.

The high pH values in the surface waters at all locations (when compared with those in the hypolimnion) resulted from the reduction of free CO_2 and HCO_3^- during photosynthesis. The decrease in pH in hypolimnetic waters was accentuated by varying degrees of decomposition with corresponding CO_2 and HCO_3^- increases. During summer stagnation periods, the vertical distribution of free CO_2 is generally the inverse of oxygen distribution. Most north-temperate lakes having critical oxygen depletions in the hypolimnion are usually characterized by increases of both analytical free CO_2 and bicarbonate (i.e. expressed as alkalinity in this study). However, as indicated in Table 1.5 bicarbonate and conductivity were usually uniform with depth; thus, any change in the vertical distribution of inorganic carbon at the study locations can be attributed solely to free CO_2. The low pH and excessive CO_2 accumulations coupled with oxygen losses in the bottom waters of Gravenhurst Bay are conditions which suggest the presence of a classical phosphorus re-cycling mechanism.

Chlorophyll a measures the amount of photosynthetic green pigment in algae and can be used as an indication of the extent of biological activity at the time of sampling. Experience has indicated that concentrations (on an ice-free yearly average) between 0 and 3 μg l^{-1} are low and indicate low to moderate algal densities.

Concentrations between 3.0 and 6.0 μg l^{-1}, although moderately high, may be considered acceptable for most water-oriented recreational pursuits. Levels greater than 6 μg l^{-1} reflect high algal populations. At these higher levels a reduction of quality for recreational activities such as swimming and water skiing may be expected, as well as the diminution of the lake's aesthetic quality. As indicated in Table 1.6 and Figure 22 of Appendix 'A', chlorophyll levels were low throughout the study area reflecting good water quality conditions, except Gravenhurst Bay where troublesome levels of algae materialized.

Water clarity, which is one of the most important parameters used in defining water quality is determined using a Secchi disc. Personnel of the Biology Section have observed that a near-hyperbolic relationship exists between chlorophyll a concentrations and Secchi disc readings for lakes in areas where the Precambrian Shield is exposed. As expected, a good deal of scatter was apparent when individual ice-free transparency values were plotted against single chlorophyll a concentrations; however, a good correlation was demonstrated between mean summer Secchi disc readings and mean chlorophyll a values. Figure 1.3 describes this relationship for 945 sets of data collected from approximately sixty recreational lakes located primarily in Southern Ontario. Points for eutrophic lakes which are characterized by high chlorophyll a concentrations and poor water clarity are situated along the vertical axis of the hyperbola while oligotrophic waters which have low chlorophyll levels and allow significant light penetration lie along the horizontal limb. Data for mesotrophic lakes could be dispersed about the middle section of the curve. Edmondson (1972) cautions that "the relation is not expected to be close because the visibility of the Secchi disc is more affected by the number of particles scattering light than by the chlorophyll content of the particles". However, Edmondson concludes that, "the correlation works only because a plankton population with a large number of cells and colonies tends to have more chlorophyll than a very small population." As indicated, all stations were

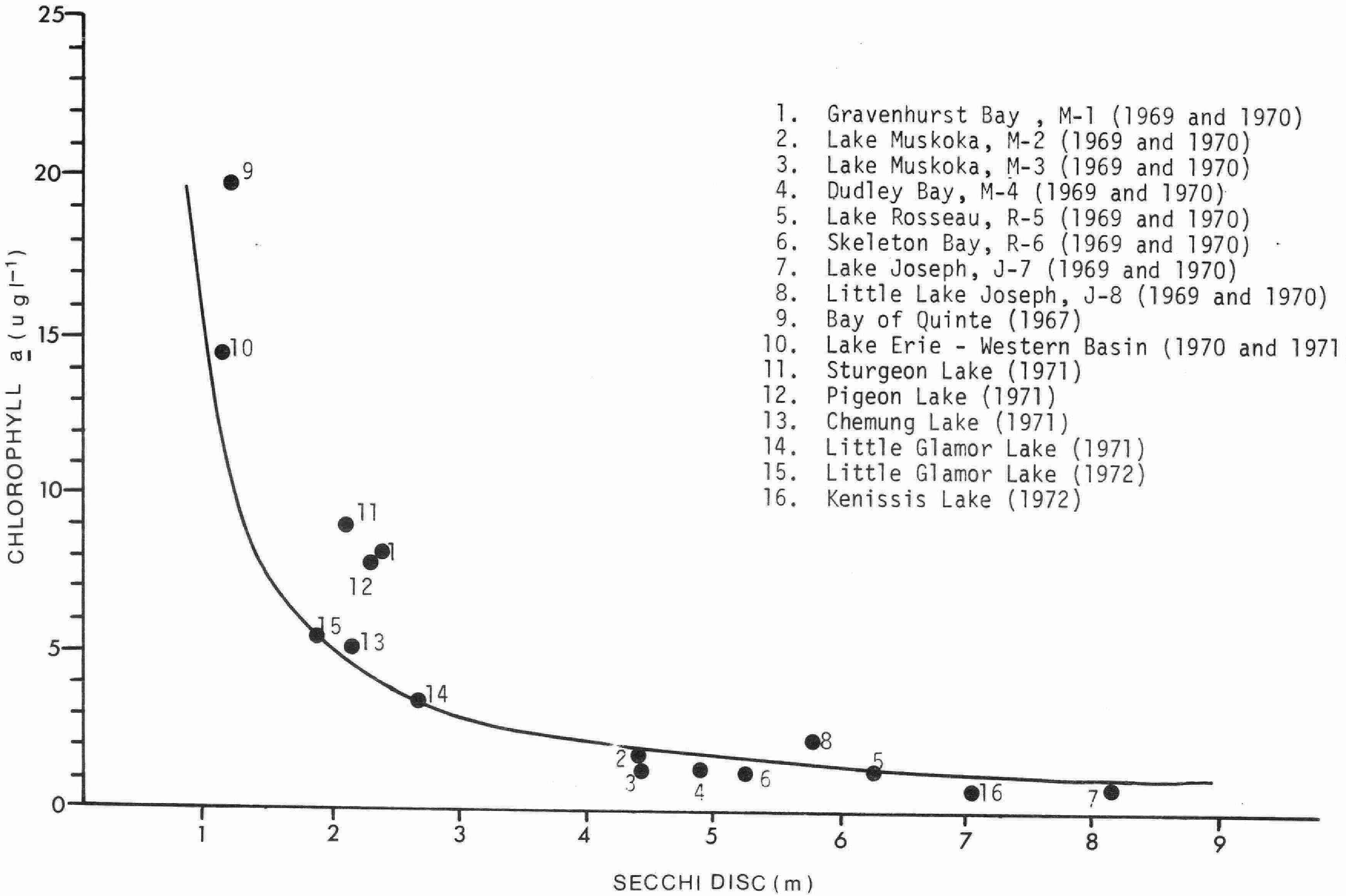

Figure 1.3: The relationship between chlorophyll a and Secchi disc for eight locations in the study area and other recreational lakes in the province. All data are yearly means.

positioned in the oligotrophic section of the curve except for M-1 which was in close proximity to the enriched waters of Sturgeon and Pigeon Lakes - two highly developed lakes of the Kawartha - Trent Watershed. Of some interest is that at low chlorophyll levels (i.e. 0.5 $\mu g\ l^{-1}$), a wide range in Secchi values occurs, whereas at high chlorophyll values, the range in transparency is much narrower. Consequently, a considerable decrease in algal densities would be necessary before an improvement in water clarity would become publicly noticeable. Edmondson (1972) suggested that, "this relation might well give rise to a subjective public impression of a threshold effect or "trigger" effect."

Phosphorus, nitrogen and eutrophication

A number of authors (Ball 1948, Rodhe 1948, Hasler and Einsele 1948, Hutchinson and Bowen 1950, Gerloff and Skoog 1957, Putnam and Olson 1960, Wetzel 1966 and Edmondson 1970) have demonstrated that phosphorus is the key element limiting algal and plant growth in the aquatic environment. Sawyer (1947) suggested that excessive algal growths will not materialize as long as total phosphorus and inorganic nitrogen concentrations do not exceed 20 and 300 $\mu g\ l^{-1}$, respectively, at the start of the growing season. Although Sawyer did not intend to establish minimum phosphorus and nitrogen criteria, many authorities and scientists, with reservations, have confirmed and used these values as "standards". It is of interest to examine spring-time phosphorus and nitrogen levels at the eight sampling locations in light of Sawyer's hypothesis (Table 1.7). As indicated, Gravenhurst Bay was the only area where phosphorus concentrations exceeded Sawyer's critical value. Inorganic nitrogen at M-1, although substantially higher than elsewhere in the study area was slightly below Sawyer's critical level.

An examination of the relative importance of nitrogen (total Kjeldahl plus nitrate) and phosphorus (total phosphorus) during the summer season is worth further comment (Table 1.7). Hutchinson (1967) indicated that phosphorus may limit production when the N/P ratio is high (i.e. >20-30:1). Conversely, when the ratio is low (i.e. <20:1) nitrogen would be expected to limit growth. The high ratios computed for all locations except Gravenhurst Bay imply that external sources of phosphorus must not gain access to the surface waters if the present

Table 1.7: Maximum total phosphorus (as $\mu g\ l^{-1}$ P) and inorganic nitrogen (free ammonia, nitrate and nitrite as $\mu g\ l^{-1}$ N) concentrations in the surface waters of the study area following the spring overturn. Additionally, N/P ratios during the summer stratification periods are listed. Nitrogen includes total Kjeldahl and nitrate.

	Phosphorus	Nitrogen	N/P
Lake Joseph	10	162	40.6
Lake Rosseau	10	213	39.2
Lake Muskoka (M-2)	18	214	46.2
Lake Muskoka (M-3)	20	210	32.6
Little Lake Joseph	12	133	35.4
Skeleton Bay	11	224	43.1
Dudley Bay	15	204	53.9
Gravenhurst Bay	68	286	11.1

quality is to be guaranteed, since additional phosphorus would allow for utilization of the available nitrogen to increase algal production. Brydges (1971a) found a direct relationship between chlorophyll a and total phosphorus using data collected for three consecutive years from Lake Erie. Chlorophyll-phosphorus values for the Muskoka Lakes as well as for Precambrian Lakes Riley, Silver and Little Panache were readily incorporated (Figure 1.4) into Brydges (1971a) relationship:

$$\text{Chlorophyll } \underline{a} = -2.1 + 0.25 \text{ (total P)}.$$

In view of the close relationship between Brydges (1971a) Lake Erie information and our inland lakes data and the fact that the enriched waters of Gravenhurst Bay are characterized by high levels of blue-green algae including *Anabaena spp.* - one form which is capable of fixing atmospheric nitrogen in the absence of other inorganic forms - it is readily apparent that a reduction in total phosphorus offers the greatest potential for effectively reducing chlorophyll concentrations and ameliorating "water-bloom" conditions.

Water quality ranking of Muskoka Lakes

Recently Michalski and Conroy (1972) proposed a water quality ranking system for lakes of Precambrian origin. High quality was equated with low biological activity and suitability for most water-oriented recreational activities, including the absence of conditions detrimental to cold-water fish populations. Low quality was associated with indications of high biological activity and conditions not conducive to most water-oriented recreational activities. The point of view was recognized however, that lakes having high biological activity may be considered high in quality purely from a fisheries standpoint. The parameters used and their relation to high water quality are presented below.

Parameter	Relation to high water quality
Mean depth	direct
Secchi disc depth	direct
Chlorophyll a	inverse
Oxygen distribution in the mid-summer	direct
Morpho-edaphic index (Ryder 1965)	inverse
Fe to P ratio at 1m above bottom under anaerobic conditions	direct

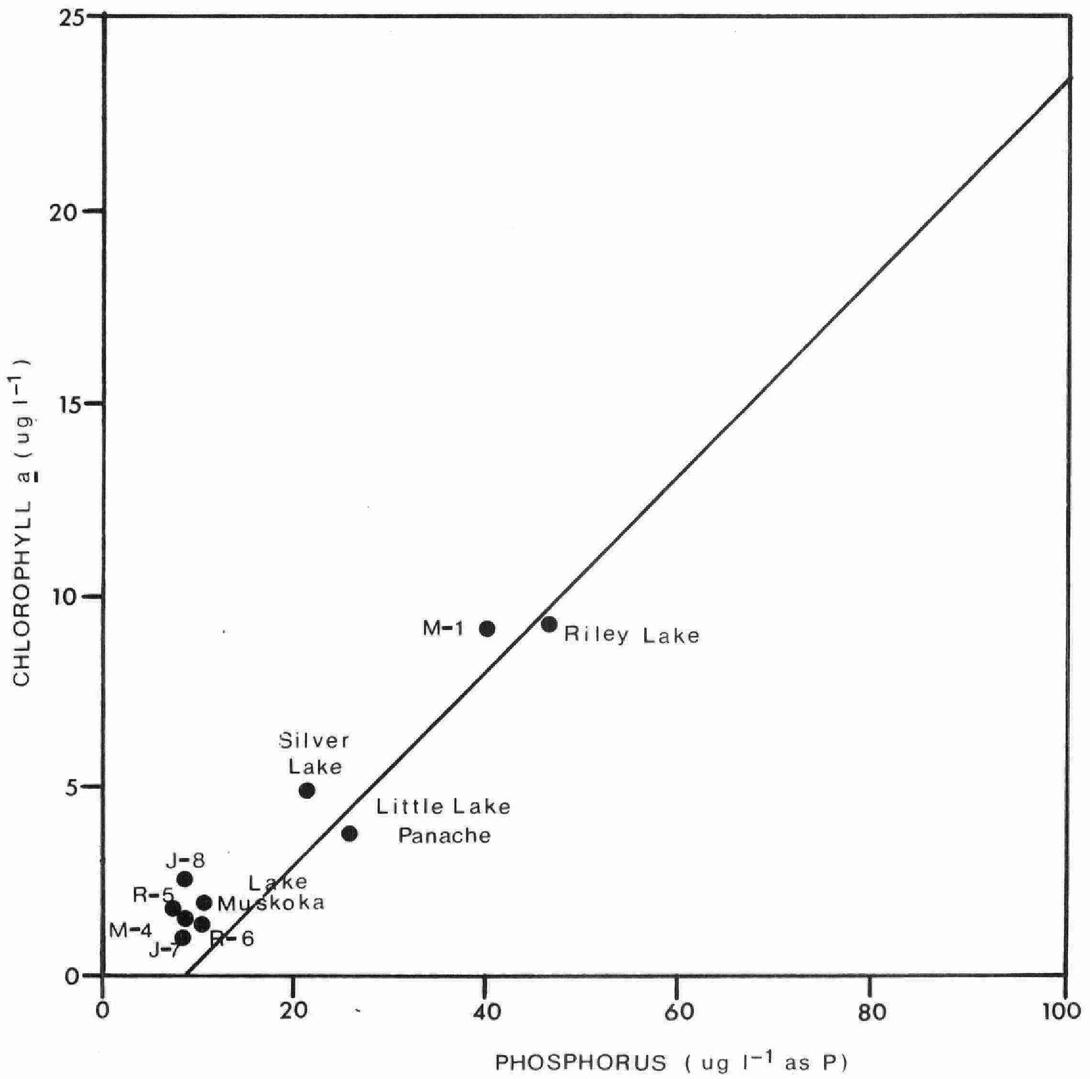

Figure 1.4: Mean chlorophyll a versus mean total phosphorus values in the study area (1969 and 1970) as well as for Riley Lake near Gravenhurst (1969), Little Lake Panache near Sudbury (1968) and Silver Lake in Port Carling (1969 and 1970).

In Table 1.8, the Muskoka stations are arranged in a high to low water quality order on the basis of average proportionate values developed from each of the measured parameters (for ranking methodology see Michalski and Conroy 1972). In general, a ranking greater than 6 (Lakes Joseph, Rosseau, Muskoka and Little Joseph) reflects excellent water quality, while a ranking between 3 and 6 (Dudley and Skeleton Bays) indicates water quality conditions which are vulnerable to artificial waste inputs. Extremely poor water quality prevailed in Gravenhurst Bay where a ranking of 0.0 was computed.

Table 1.8: Ranking of the Muskoka Lakes study locations according to proportionate rankings for selected parameters. Values for each parameter are indicated in brackets.

Lake	PROPORTIONATE RANKINGS						AVERAGE RANK
	Mean Depth	Secchi Disc	Chlorophyll a	Oxygen Distribution	Morphoedaphic Index	Fe/P	
Joseph	9.8 (25.3)	10.0 (8.1)	10.0 (1.1)	10.0 (a)	10.0 (0.5)	- (-)	9.9
Rosseau	10.0 (25.5)	6.5 (6.2)	9.1 (1.7)	10.0 (a)	10.0 (0.5)	- (-)	9.5
Muskoka	5.3 (16.8)	3.1 (4.4)	8.9 (1.9)	10.0 (a)	7.6 (0.8)	- (-)	6.8
Little Lake Joseph	5.4 (17.0)	6.0 (5.9)	8.1 (2.5)	3.3 (b)	9.1 (0.7)	- (-)	6.4
Skeleton Bay	1.4 (9.4)	4.6 (5.2)	9.4 (1.7)	3.3 (b)	4.6 (1.2)	- (-)	4.6
Dudley Bay	0.0 (6.7)	4.0 (4.9)	9.4 (1.5)	3.3 (b)	1.4 (1.6)	- (-)	3.6
Gravenhurst Bay	0.2 (7.0)	0.0 (2.7)	0.0 (8.6)	0.0 (c)	0.0 (1.8)	0.0 (10.1)	0.0

Values for types of oxygen distribution were subjectively applied following Michalski and Conroy (1972).

a. Orthograde - Oxygen concentrations are non-diminishing with depth.

b. Clinograde - Oxygen concentrations diminish with depth.

or

Positive or negative heterograde - Increases or decreases in oxygen concentrations in the thermocline or upper hypolimnial regions.

c. Anaerobic conditions at 1 m above bottom.

CHAPTER 2

PHYTOPLANKTON STOCKS

AND

PRIMARY PRODUCTION

CHAPTER 2 - PHYTOPLANKTON STOCKS AND PRIMARY PRODUCTION

INTRODUCTION

At present there is a general paucity of published quantitative and qualitative information on standing stocks of phytoplankton and production rates in Ontario's Precambrian lakes. Notable efforts are those of Christie (1968 and 1969) on phytoplankton communities and limiting nutrients in several Shield lakes of the Haliburton Highland region, Johnson et al. (1969) on the effects of acid-uranium wastes on phytoplankton stocks and primary productivity in lakes near Elliot Lake and Schindler and Nighswander (1970) on phytoplankton biomass and productivity of Clear Lake in the Township of Haliburton. Recently, Schindler and Holmgren (1971) presented primary production data and phytoplankton information from several lakes in the Experimental Lakes Area of Northwestern Ontario and developed a system for classifying the lakes in terms of phytoplankton species composition and production-depth curves. This chapter presents data on phytoplankton densities, species composition and primary production rates in the Muskoka Lakes and considers these findings in assessing trophic conditions throughout the system. Additionally, the data will be important for use as base-line information for future comparisons of water quality.

METHODS

Phytoplankton analyses

Phytoplankton samples representing the euphotic zone were collected on each sampling day at the eight locations. The samples were preserved with sufficient Lugol's solution at the time of sampling to impart a dark orange colour to the water and were transported to the laboratories in Toronto for analyses.

The algal samples were concentrated by allowing the cells to settle for 72-96 hours, followed by siphoning the overlying liquid. Subsequently, the cells were re-suspended and a 1ml aliquot was pipetted into a Sedgwick-Rafter counting cell. Most of the algal forms were identified to genus at a magnificant of 220X. Where accurate identifications were impossible, wet mounts were prepared and examined at higher magnifications. Quantitative results were expressed as areal standard units per millilitre for comparison with estimates of primary production. One areal standard unit is equal to an area of 400 square microns (Whipple 1914), and was employed because it is as useful as cell volume and is preferred over cell numbers when relating primary productivity to standing stocks (Paasche 1960). Depending on the density of the concentrate, strips or fields were counted. Between 250 and 600 organisms per aliquot were identified and measured. The Bacillariophyceae were speciated following acid digestion or incineration of a 15ml portion of the concentrate and mounting in Hyrax. These algae were examined at a magnification of 1200X or 1500X and were counted by starting at one edge of the coverslip and scanning one or more rows across the mount. Valves were counted as one-half frustule; broken valves were not counted. Conversion to areal standard unit values was accomplished by direct proportion. Taxonomic references included those of Huber-Pestalozzi (1938, 1941, 1942 and 1950), Prescott (1951), Patrick and Reimer (1966), Tiffany and Britton (1952), Smith (1950), Sieminska (1964) and Skuja (1948).

Diversity in phytoplankton communities

The index of diversity, I (after Margalef 1958), for each composite sample at the eight sampling sites was calculated as

$$I = \frac{S-1}{\log_e N}$$

where S is the total number of species and N is the total number of individuals. Margalef's I is assumed to be independent of the numbers of individuals examined. Development of I using cumulative

counts of algae indicated that this assumption was correct, provided that at least 50 individuals were examined. Between 250 and 600 individuals per sample were examined.

Primary production

A number of problems exist in measuring primary production using the oxygen evolution or pH change techniques in most Precambrian Shield lakes. For example, the oxygen method is too insensitive for short-term exposures owing to the moderately productive nature of the lakes. Also, preliminary evidence indicates that conversion of oxygen evolved to the more conventional carbon measurements would be questionable. Estimates of primary production were made at each station once per month May - September in 1969 and every two weeks at Stations M-1, J-7 and J-8 in 1970 using the ^{14}C method. Samples of lake water were taken from six or seven depths to the approximate location of the 1% incident light level using a Van Dorn water sampler. Water from each depth was dispensed into three clear and one dark (opaque) glass stoppered 190ml bottles. Exactly 1.0ml of radioactive $NaH^{14}CO_3$ (New England Nuclear Corporation) with activity of 2.5 - 10μ Ci ml^{-1} was added to each bottle using a hypodermic syringe. The bottles were clamped on spacers and suspended at the depths from which they were originally taken (Figure 2.1 a and 2.1 b). Effects of wave action on the float-spacer system assisted in maintaining the phytoplankton in suspension. An incubation period of 4-5 hours (usually 10:00 a.m. - 3:00 p.m. Eastern Daylight Saving Time) was used as this appears adequate for significant uptake of carbon fixation and yet sufficiently limited to minimize bottle effects (Vollenweider and Nauwerck 1961).

During the incubation period, 40-ounce samples were collected and preserved for phytoplankton analyses from depths similar to those of the *in situ* samples and 190ml samples were taken for inorganic carbon analyses and treated as outlined later Inorganic carbon re: primary productivity (page 27).

Primary production was arrested by adding mercuric chloride (0.7g $HgCl_2$ per 1.0 liter water) and, within several hours, the algae were

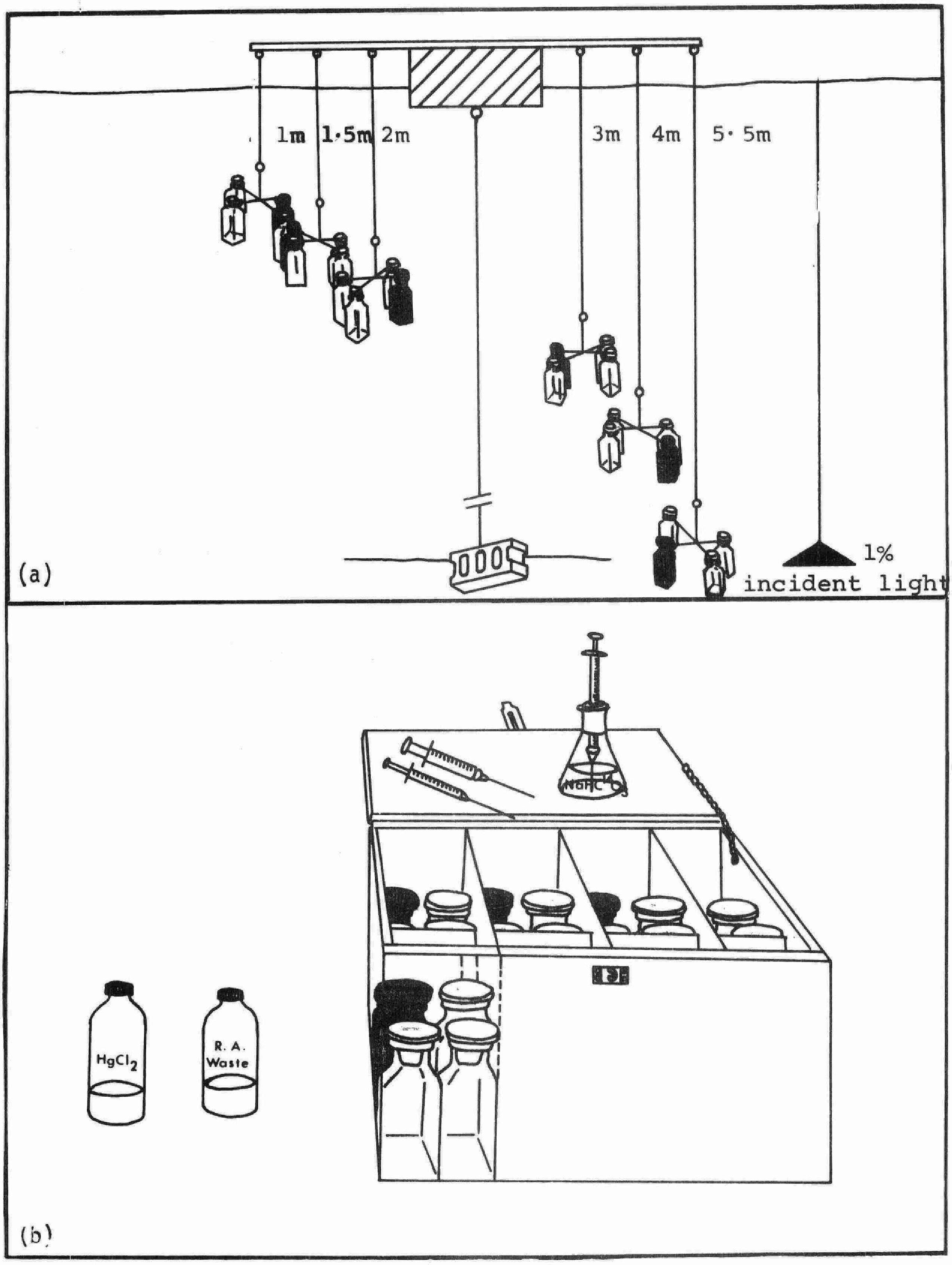

Figure 2.1: Diagrammatic representation (a) for determining the photosynthetic activity of the euphotic zone and (b) field equipment: 10ml syringe, 25ml syringe, 1ml syringe (for dispensing ^{14}C) and sterile ^{14}C reservoir, light and dark bottles $HgCl_2$, and container for storing radioactive waste material.

recovered on 0.45µ Millipore filters, using a vacuum pump with pressure not exceeding 60cm of mercury. Each filter was rinsed with four separate 15ml aliquots of distilled water, dried with an IR light source at a distance of 0.2-0.4m and placed in a scintillation-counting medium of 0.01% 1,4-bis-[2-(4-methyl-5-phenyloxazolyl)] - benzene and 0.4% 2,5-diphenyloxazole in toluene. The samples were transported to the Ministry of the Environment's Laboratory in Toronto where the ^{14}C activity of the algae was determined with a Packard Tricarb spectrometer.

The use of mercuric chloride as a preservative was evaluated by comparing the activity of treated algae with that of samples filtered immediately after incubation. As indicated in Table 2.1, the maximum activity and production rate (mg C m^{-3} hr^{-1}) was higher in the untreated samples although the calculated areal rate (mg C m^{-2} hr^{-1}) was higher for the preserved samples. The slight differences observed are considered to be within the limits of precision of the technique.

There is some difference of opinion whether production follows the daily insolation or is more efficient before mid-day. Goldman (1968) indicated the former response, but several authors (Doty and Oguri 1957, Ohle 1958 and Vollenweider and Nauwerck 1961) demonstrated the occurrence of asymmetrical day-curves. The possibility of asymmetrical day-curves was considered at Stations M-1 and J-7 on July 29 and August 11, 1970, respectively. Individual productivity sets four hours in duration were lowered at 6:00 a.m., 10:00 a.m., 2:00 p.m. and 6:00 p.m. (Eastern Daylight Saving Time). Cumulative production rates plotted against cumulative solar radiation provided straight lines for both sets of data (Figure 2.2), suggesting that photosynthetic activities in the Muskoka Lakes follows the daily solar radiation.

During the summer of 1970, a note was published (Pugh 1970) which pointed out that under-estimates of production occurred from self-absorption when toluene fluors were used. Although Millipore filters may be cleared if dry prior to immersing in a toluene fluor, the filters do not dissolve; accordingly, self-absorption may be high. We attempted to compensate for this potential error by converting our areal standard unit data for the eight stations

Table 2.1: Comparison of activities and productivity rates for unpreserved samples and those treated with Hg Cl².

	Unpreserved Samples		Preserved Samples	
Depth (m)	Activity (dpm)	Productivity (mg C m^{-3} hr^{-1})	Activity (dpm)	Productivity (mg C m^{-3} hr^{-1})
Surface	95,174	3.51	80,001	3.41
1	64,146	3.01	50,028	2.23
1.5	30,111	1.34	75,311	3.28
2.0	22,049	0.98	22,754	1.05
2.5	22,960	1.10	28,588	1.35
4.0	2,926	0.15	6,138	0.31
6.0	1,598	0.09	3,122	0.17
		6.49 mg C m^{-2} hr^{-1}		7.93 mg C m^{-2} hr^{-1}

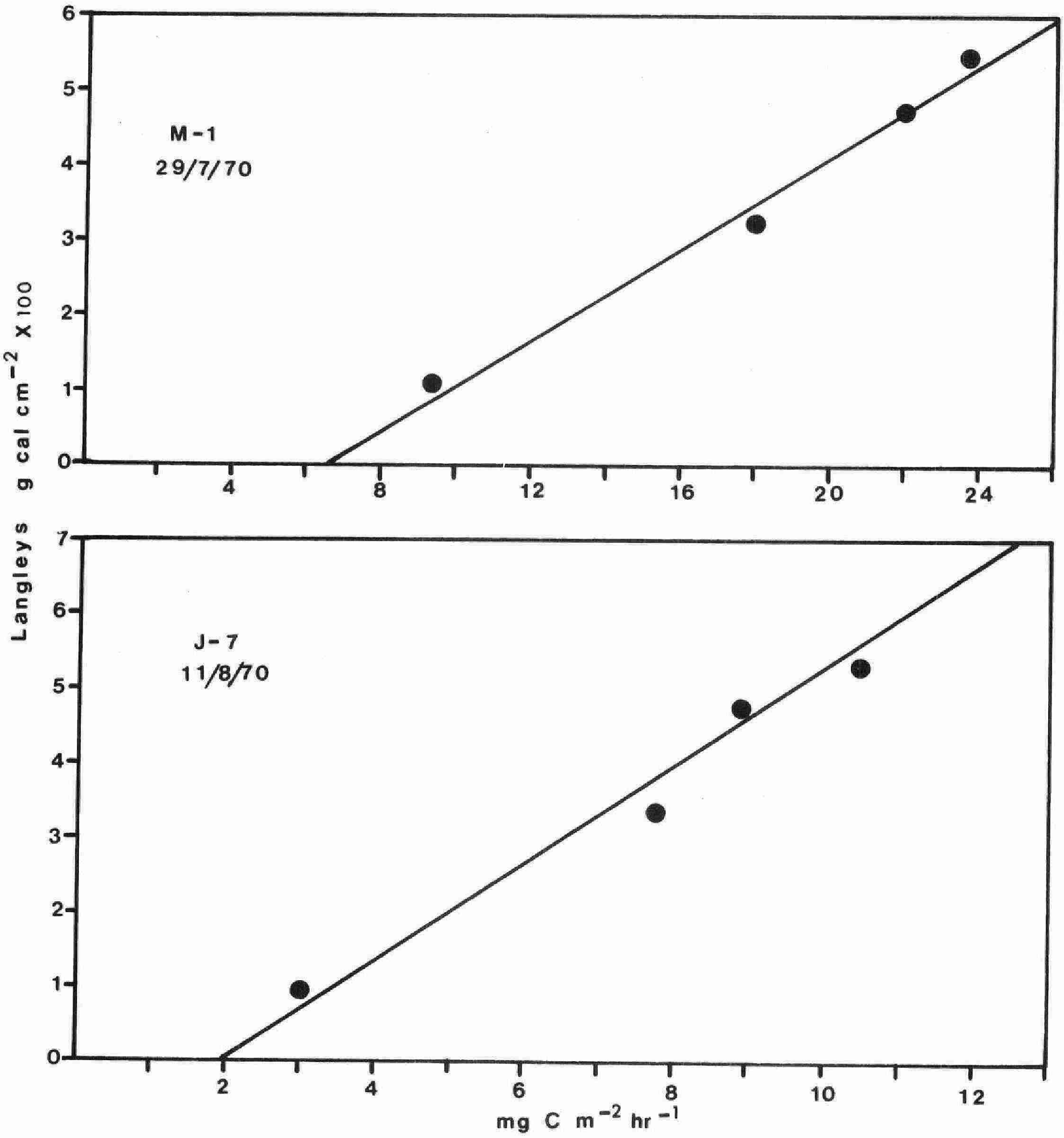

Figure 2.2: Cumulative productivity rates (mg C m^{-2} hr^{-1}) plotted against cumulative solar radiation (g cal cm^{-2}) at Stations M-1 and J-7 on July 29 and August 11, 1970, respectively.

to milligrams of algae trapped on the filter and employed Table 1 of Pugh (1970) to develop an internal standard. The error owing to self-absorption proved minimal (i.e. 0.01 - 2.5%) for low productivity waters but was as high as 15.5% for waters with high standing stocks of phytoplankton.

Utilizing the computer programme OWRASSIM, the uptake of C assimilated by photoplankton was estimated from the equation:

$$\frac{\text{C assimilated}}{\text{C available (W+X)}} = \frac{{}^{14}\text{C assimilated (Y)}}{{}^{14}\text{C available (Z)}} \cdot K$$

from which

$$\text{C assimilated} = K \frac{Y}{Z} (W+X) \text{ mg C m}^{-3}$$

where Y is the activity of filtered phytoplankton corrected for dark bottle assimilation and self-absorption, W is the inorganic carbon concentration in the lake water (mg C m^{-3}), X is the concentration of inorganic ^{14}C added to the bottles (mg C m^{-3}), Z is the activity of inorganic ^{14}C added to the bottles and K is 1.05 and corrects for isotopic discrimination (Strickland 1960).

The programme was designed to determine the mean integral primary production (mg C m^{-2} hr^{-1}) as well as productivity in (mg C m^{-3} hr^{-1}) for each depth. Correction to full-day photosynthetic rates was accomplished by multiplying the 4-5 hour production values by the ratio:

$$\frac{I_0 \text{ daily}}{I_0 \text{ for the incubation period}}$$

where I_0 is the surface solar radiation expressed in langleys.

Inorganic carbon re: primary productivity

In estimating the rate of carbon assimilated by algae it is necessary to know with sufficient accuracy the concentration of inorganic carbon (i.e. free $CO_2+HCO_3^-+CO_3^=$) in the water. Calculations of inorganic carbon based on pH, alkalinity and temperature of titration (A.P.H.A. et al. 1965, Saunders et al. 1962) was not advisable because

Table 2.2: Summary of phytoplanktonic data collected from the eight sampling locations during the ice-free periods of 1969 and 1970. All results are expressed as areal standard units per millilitre.

Location	1969			1970		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Lakes						
Joseph (J-7)	1,153	31	402	1,207	41	533
Rosseau (R-5)	1,880	54	479	1,449	63	546
Muskoka (M-2)	1,469	98	602	1,455	202	601
Muskoka (M-3)	750	136	419	1,549	163	788
Bays						
Little Lake Joseph (J-8)	1,945	187	733	1,263	77	618
Skeleton (R-6)	1,869	200	890	1,776	504	1,031
Dudley (M-4)	1,285	260	646	1,311	413	703
Gravenhurst (M-1)	6,402	134	2,686	5,419	350	2,320

of the low levels present in Precambrian soft water lakes (Johnson et al. 1970, Schindler and Holmgren 1971) and inherent difficulties in measuring pH. In 1969, a technique was employed which separated and concentrated inorganic carbon from a 40-ounce sample bottle allowing a desired precision of 0.1 mg l^{-1} (Johnson and Michalski 1970). In 1970 gas chromatographic techniques were utilized. For both years, the pH of all samples was adjusted in the field to about 12.5 using either pellets of NaOH washed in 10% HCL or 50% analytical grade NaOH dispensed from small dropper bottles (a fresh bottle for each depth series was used).

RESULTS

Standing stocks of phytoplankton - quantitative aspects

Two distinct areas of algal abundance were apparent - Gravenhurst Bay and the remainder of the study area. As indicated in Table 2.2, maximum and mean areal standard unit values were four to five times higher at Station M-1 than elsewhere in the system. Considering the main lakes only, standing stocks of phytoplankton increased in order from Lake Joseph to Lake Rosseau to Lake Muskoka. Generally higher phytoplankton levels were measured at the "Bay" locations than at the corresponding main lake sampling sites. For example, mean areal standard unit values for 1969 were 890 for Skeleton Bay (R-6) and 479 for Lake Rosseau (R-5). Corresponding values for 1970 were 1,031 and 546 a.s.u. ml^{-1} for Skeleton Bay and Lake Rosseau, respectively. In Gravenhurst Bay, counts were as high as 6,402 a.s.u. ml^{-1} (October 29, 1969); in contrast, the highest a.s.u. value reported elsewhere was 1,945 (Little Lake Joseph; August 21, 1969).

The seasonal patterns in phytoplankton development (in a.s.u. per ml) and successional changes for the major taxonomic classifications (expressed as percent composition) are presented in Figure 23 to 30 of Appendix A. At stations located in Lake Muskoka (M-2 and M-3), in Dudley and Skeleton Bays (M-4 and R-6) and in Little Lake Joseph (J-8), a bimodal pattern in phytoplankton development occurred for both years; the first materialized during

May and/or June while the second occurred during the latter part of August and throughout September. The spring algal peaks at stations located in Lake Rosseau and Joseph were not recorded. Significantly, in Gravenhurst Bay, a definite pattern of development was not detected as relatively high phytoplankton numbers were encountered during the mid-summer months. Although "water-bloom" conditions were of short-term duration in 1969 (i.e. occurring after the fall overturn - October 29), algal densities during the late summer and early fall months of 1970 were sufficiently high to create obnoxious surface scums.

Standing stocks of phytoplankton - qualitative aspects

In general, species composition and seasonal successions were similar for 1969 and 1970. Bacillariophycean (diatoms), chrysophycean and cryptophycean algae predominated during the spring seasons at the main lake stations and at Dudley, Skeleton and Little Joseph Bays. In Gravenhurst Bay, representatives of the Chrysophyceae were noticeably absent. During the early summer months myxophycean (blue-green) algae predominated at all sampling locations except for Gravenhurst Bay where high numbers of Chlorophyceae (green algae), Dinophyceae, Cryptophyceae, and Bacillariophyceae were encountered. The late summer and early fall samples at all stations were characterized almost exclusively by blue-green algae. In addition to blue-green species, the late September and October flora consisted of moderate to moderately high numbers of diatoms.

Specifically, early spring stocks in Gravenhurst Bay were dominated by high numbers of diatoms including *Synedra rumpens* Kütz, *Asterionella formosa* Hass., *Cyclotella stelligera* Cl. and Grun. and *Fragilaria crotenensis* Kitt. and the cryptophycean algae *Cryptomonas erosa* Ehr. and *Rhodomonas minuta* Skuja. Elsewhere in the study area the most important components of the early spring flora were the diatoms *Rhizosolenia eriensis* H.L. Smith and *A. formosa*, the chrysophycean algae *Dinobryon sertularia* Ehr., *D. bavaricum* Imhoff and *Mallomonas* spp., and *R. minuta*. The highest a.s.u. value (5,294) recorded for the spring maximum occurred on May 13, 1969 at M-1 owing to the abundance of *S. rumpens* (2,778 a.s.u. ml^{-1}), *A. formosa* (399 a.s.u. ml^{-1}), *C. stelligera* (181 a.s.u. ml^{-1}) *C. erosa* (933 a.s.u. ml^{-1}) and *R. minuta* (813 a.s.u. ml^{-1}).

During the summer months, the Gravenhurst Bay samples contained exceptionally high numbers of green algae including Staurastrum spp., Sphaerocystis Schroeteri Chodat and Chlamydomonas spp. and the dinophycean species Ceratium hirundinella (O. Müll.) Dujardin. Additionally, moderate to moderately high numbers of A. formosa, F. crotonensis, C. erosa and R. minuta were encountered. Most of the aforementioned species were observed in samples taken from Lakes Muskoka, Rosseau, Joseph and Little Joseph and from Dudley and Skeleton Bays; however, without exception numbers were significantly lower than those found in Gravenhurst Bay. For example, a maximum value of 307 a.s.u. ml^{-1} for Chlamydomonas spp. was recorded at M-1 on May 23, 1969. Elsewhere in the system, values for this genus in excess of 25 a.s.u. ml^{-1} were rarely encountered. Similarly, C. hirundenella, attaining a maximum of 2,883 a.s.u. ml^{-1} on July 30, 1969 at M-1, was occasionally observed in Lake Muskoka and Dudley Bay but was never reported from samples collected above Port Carling. During these summer months the most important plankters in the main lakes and in Dudley, Skeleton and Little Joseph Bays included three species of Aphanothece (A. nidulans P. Richter, A. gelatinosa (Henn.) Lemmermann and A. clathrata W. and G.S. West), Chroococcus limneticus Lemmerman, Gomphosphaeria lacustris Chodat, Aphanocapsa elachista West and West and Merismopedia tennuissima Lemmermann. Also, most samples contained very low to moderate numbers of Chrysophyceae (i.e. Synura uvella Ehr., D. sertularia and D. bavaricum) and a number of diatoms including A. formosa, R. eriensis, F. crotonensis, Tabellaria fenestrata (Lyngb.) Kütz. Cyclotella compta (Ehr.) Kütz., and C. stelligera. Relatively high numbers of S. rumpens were encountered only in Little Lake Joseph.

During the latter part of October 1969 and throughout August and September 1970, the waters of Gravenhurst Bay were characterized by extensive water blooms owing to excessive numbers of Aphanizomenon flos-aquae (L.) Ralfs and Anabaena spp. Blue-green densities in excess of 3,000 a.s.u. ml^{-1} were regularly encountered. Conversely, at the other locations trouble-some levels of "water-bloom" forming species were not found although moderate to moderately high numbers of C. limneticus, G. lacustris, A. nidulans, A. gelatinosa, A. clathrata, A. elachista and M. tennuissima were encountered.

Additionally, some areal changes in diatom species quantity and composition were apparent. For example, A. formosa was always identified and enumerated; however, higher numbers materialized in Gravenhurst Bay (4,849 a.s.u. ml^{-1} on September 9, 1969) than elsewhere in the system where values did not exceed 54 a.s.u. ml^{-1} (Dudley Bay, October 8, 1970). Also, relatively high numbers of F. crotonensis were present in samples taken from Stations M-1, M-2, M-3 and M-4 but were observed only occasionally in the flora of Lakes Rosseau, Joseph and Little Joseph and in Skeleton Bay. Finally, R. eriensis occurred only in Lake Muskoka (i.e. Stations M-2, M-3 and M-4).

A complete species listing for each station is presented in Appendix 'B'.

Species diversity

Table 2.3 summarizes the mean, maximum and minimum indices of diversity for 1969 and 1970 at the eight locations. Diversity values were lowest at Gravenhurst Bay; similar indices were measured at the remaining seven sampling sites. In general, diversity values were highest during May and June; a decreasing trend in July and August was noted at all sampling sites.

Primary productivity

Integrals of hourly primary productivity are presented graphically with standing stocks of phytoplankton (expressed as a.s.u. ml^{-1}) and transparencies in Figures 2.3 and 2.4 while summaries of the volumetric and areal estimates are presented in Table 2.4. As expected, the highest volumetric rate of assimilation of 43.6 mg C m^{-3} hr^{-1} was found on May 28, 1969 in Gravenhurst Bay. Elsewhere in the system maximum rates rarely exceeded 5 and usually were less than 1 mg C m^{-3} hr^{-1}.

Table 2.3 Mean, maximum and minimum values of the Index of Diversity (I) for samples collected through the euphotic zones at six locations in the study area, 1969 and 1970.

Station	INDEX OF DIVERSITY 1969				1970			
	Number Samples	Maximum	Minimum	Mean	Number Samples	Maximum	Minimum	Mean
Lakes								
Joseph	21	5.9	1.9	3.4	13	4.3	1.4	3.6
Rosseau	22	4.7	2.1	3.4	10	5.2	1.9	3.3
Muskoka M-2	22	5.8	1.9	3.4	10	5.1	1.9	3.2
Muskoka M-3	22	5.3	2.3	3.7	10	4.5	2.2	3.3
Bays								
Little Lake Joseph	23	5.6	1.9	3.4	13	4.1	2.3	3.2
Skeleton	22	5.6	1.8	3.5	10	5.7	2.1	3.4
Dudley	22	4.5	2.2	3.4	9	4.0	2.3	3.2
Gravenhurst	25	4.0	1.0	2.5	22	3.3	1.1	2.1

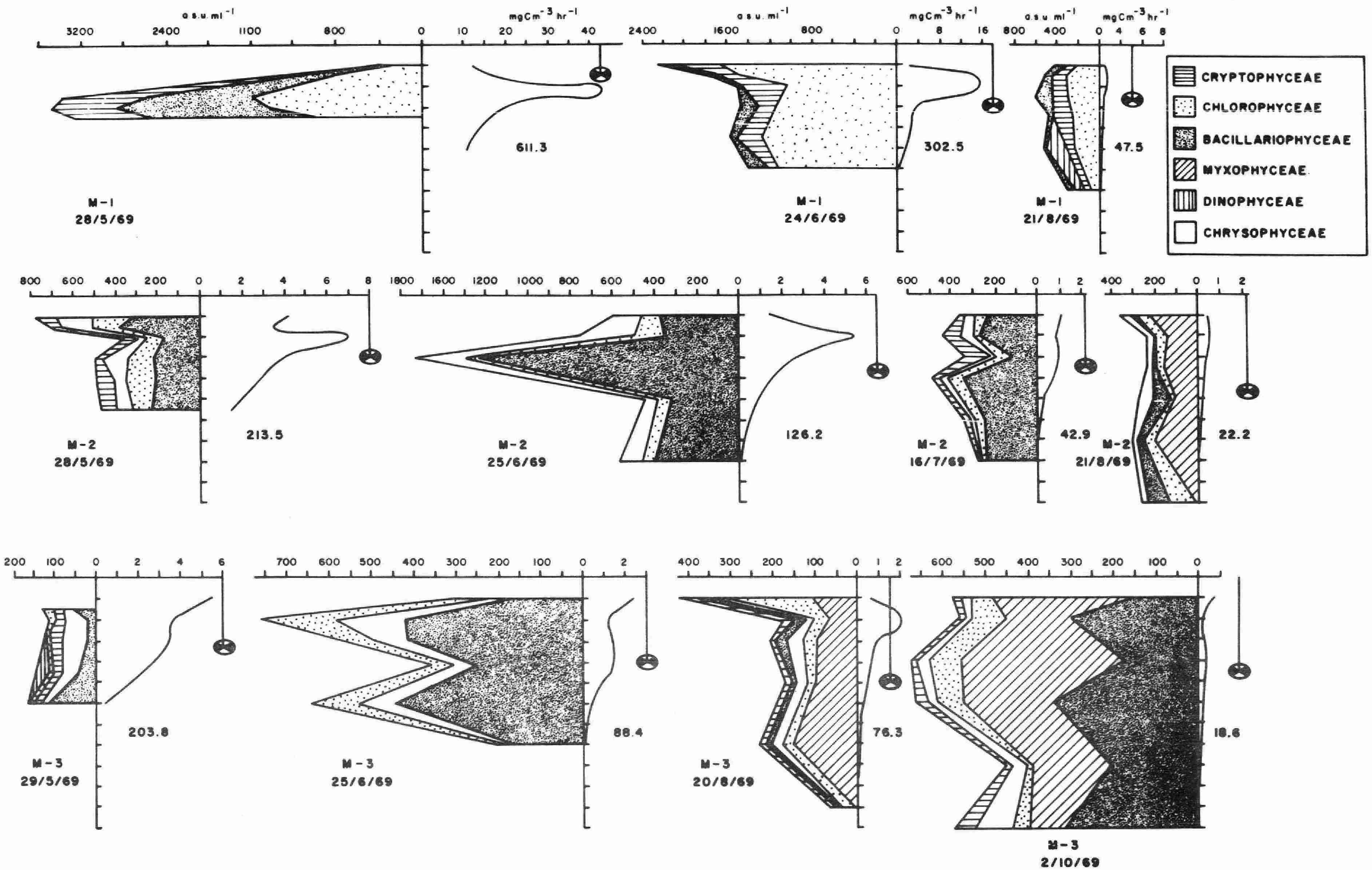

Fig. 2.3 Vertical variations in carbon assimilation ($mgCm^{-3}hr^{-1}$) and standing stocks of phytoplankton (a.s.u. ml^{-1}) by taxonomic classes at Stations M-1 (Gravenhurst Bay) and M-2 and M-3 (Lake Muskoka) on selected dates in 1969. Position of the secchi disc and daily assimilation rates ($mgCm^{-2}day^{-1}$) are also presented.

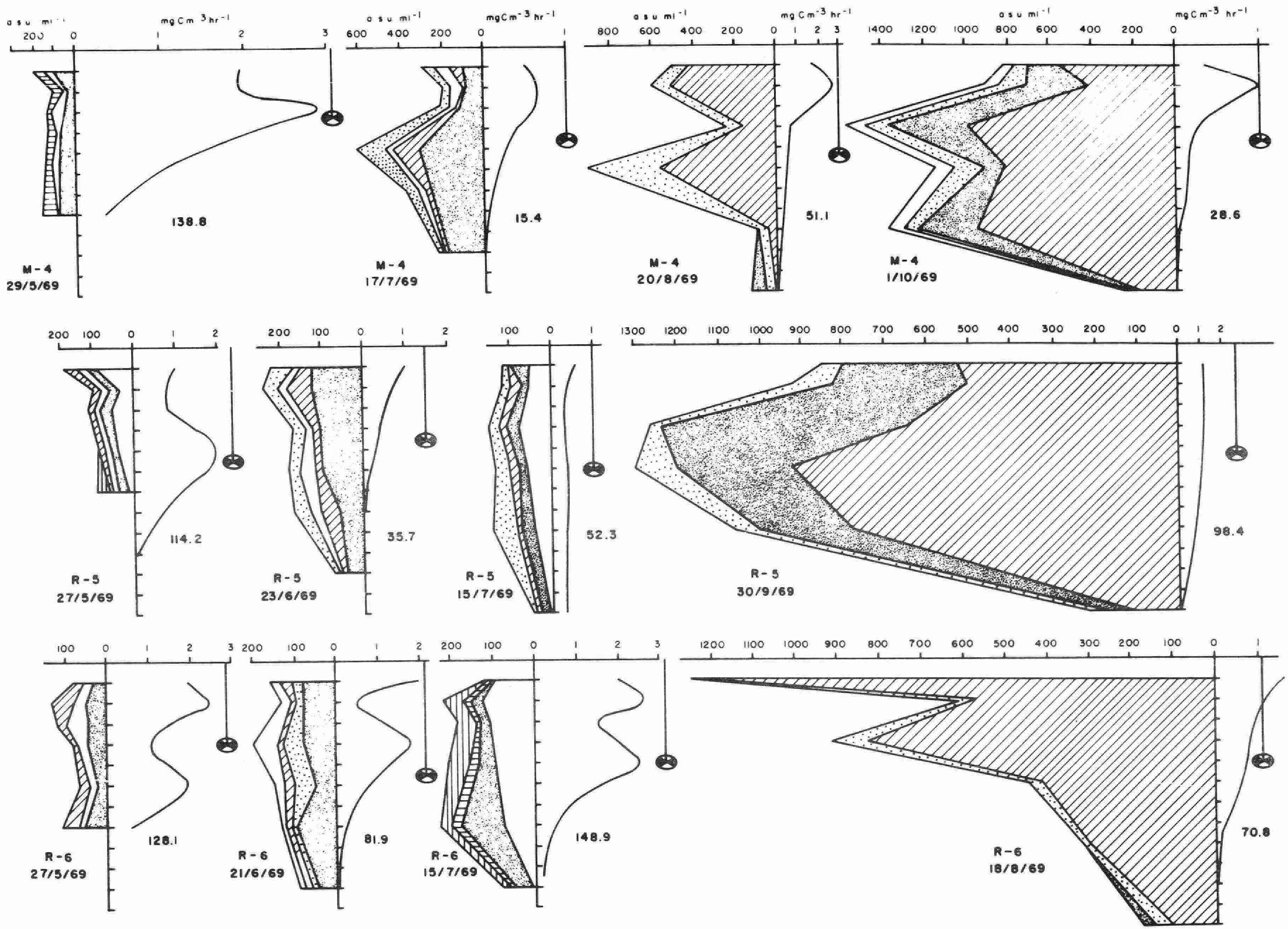

Fig. 2.3 (continued). Vertical variation in carbon assimilation ($mgCm^{-3}hr^{-1}$) and standing stocks of phytoplankton (a.s.u. ml^{-1}) by taxonomic classes at Stations M-4 (Dudley Bay), R-5 (Lake Rosseau) and R-6 (Skeleton Bay) on selected dates in 1969. Position of the secchi disc and daily assimilation rates ($mgCm^{-2}day^{-1}$) are also presented.

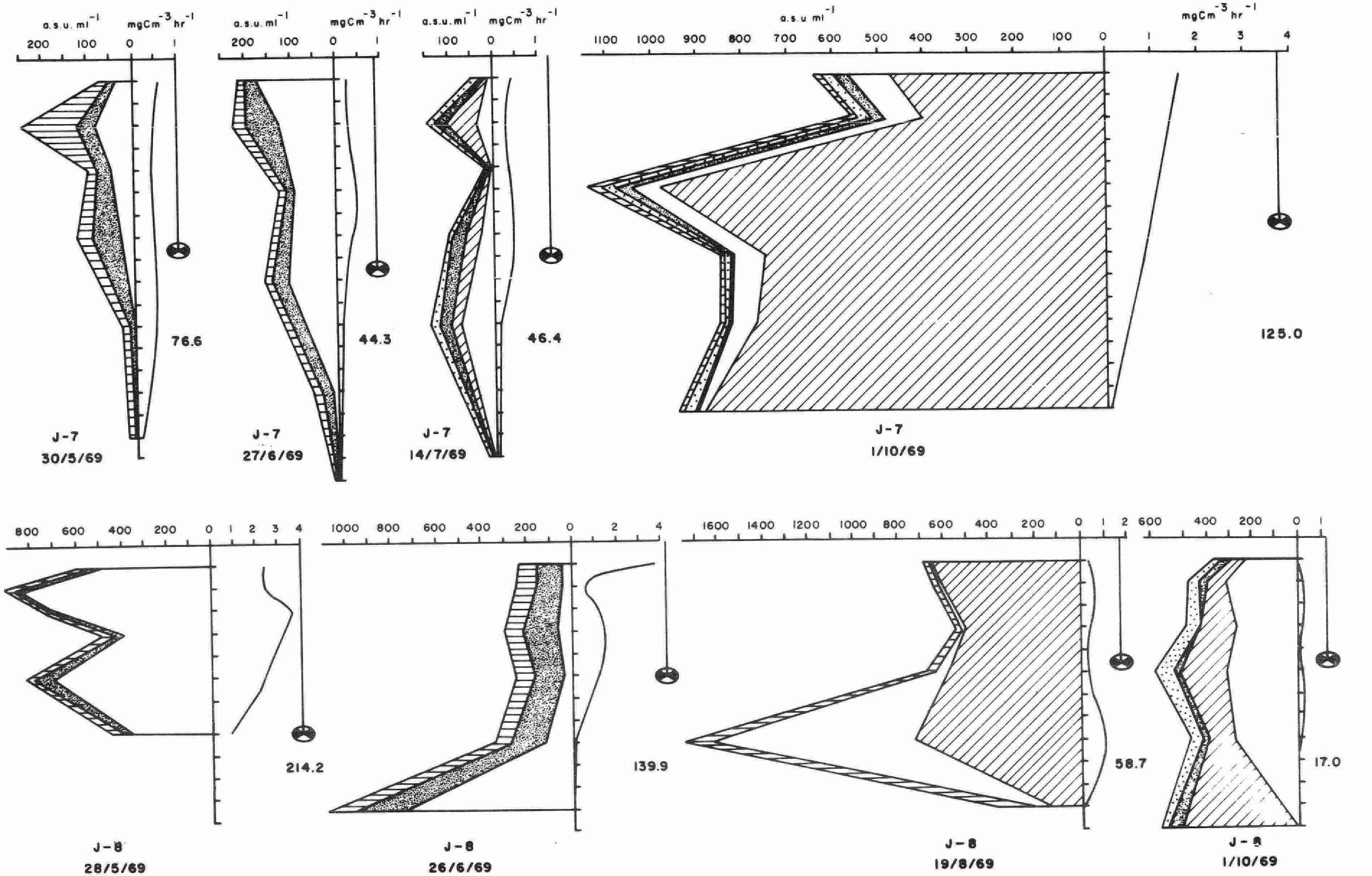

Fig. 2.3 (continued). Vertical variation in carbon assimilation (mgCm^{-3}hr^{-1}) and standing stocks of phytoplankton (a.s.u. ml^{-1}) by taxonomic classes at Stations J-7 (Lake Joseph) and J-8 (Little Lake Joseph) on selected dates in 1969. Position of the secchi disc and daily assimilation rates (mgCm^{-2}day^{-1}) are also presented.

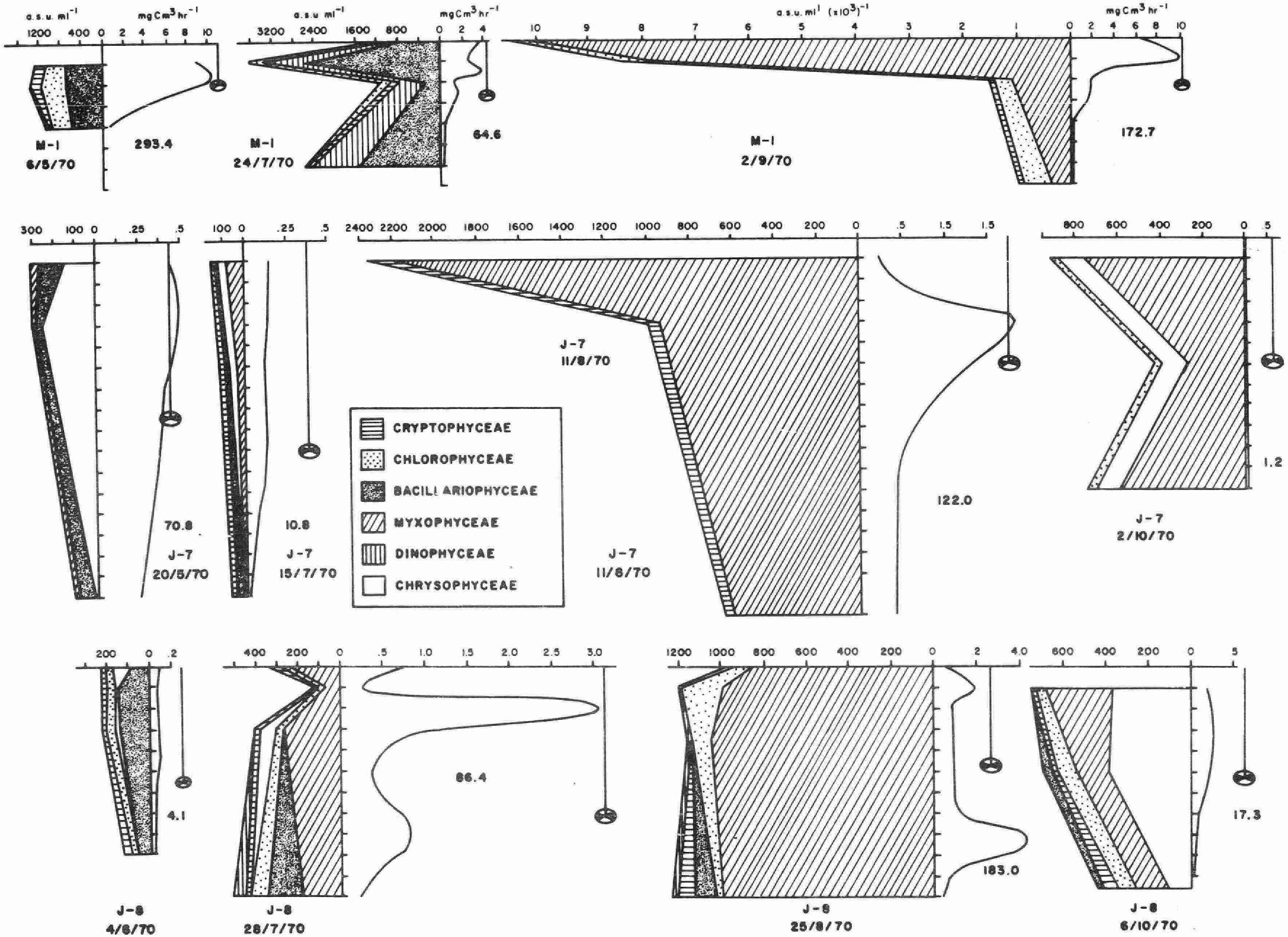

Fig. 2.4 Vertical variations in carbon assimilation ($mgCm^{-3}hr^{-1}$) and standing stocks of phytoplankton (a.s.u. ml^{-1}) by taxonomic classes at Stations M-1 (Gravenhurst Bay), J-7 (Lake Joseph) and J-8 (Little Lake Joseph) on selected dates in 1970. Position of the secchi disc and daily assimilation rates ($mgCm^{-2}day^{-1}$) are also presented.

Table 2.4: Depth of maximum volumetric carbon uptake rates expressed as mg C m^{-3} hr^{-1} and mg C m^{-3} day^{-1} and daily integrals at eight locations in 1969 and at three sampling sites in 1970. Additionally, incident light data in langleys day^{-1} are presented.

	Date	Depth (m)	Light Intensity (g cal cm^{-2})	mg C m^{-3} hr^{-1}	mg C m^{-3} day^{-1}	mg C m^{-2} day^{-1}
Lake Joseph (J-7)	30/ 5/69	1.0	688	0.6	5.8	76.6
	27/ 6/69	6.0	538	0.5	5.3	44.3
	14/ 7/69	8.0	686	0.5	4.5	46.4
	19/ 8/69	3.0	607	1.6	17.3	52.9
	1/10/69	1.0	268	1.5	16.9	125.0
	7/ 5/70	8.0	491	0.4	4.9	59.4
	20/ 5/70	4.0	695	0.5	4.8	70.8
	4/ 6/70	16.0	643	0.6	6.1	102.3
	10/ 6/70	11.0	574	0.3	2.8	17.7
	30/ 6/70	0.1	341	0.1	1.3	4.7
	15/ 7/70	3.0	345	0.1	0.9	10.8
	30/ 7/70	1.0	453	0.3	1.7	13.3
	11/ 8/70	4.0	442	1.8	18.1	122.0
	25/ 8/70	4.0	529	0.2	1.5	15.7
	9/ 9/70	2.0	76	0.1	1.0	9.0
	6/10/70	-	129	0.0	0.1	1.2
Rosseau (R-5)	27/ 5/69	5.0	340	2.1	20.2	114.2
	23/ 6/69	1.0	248	1.1	11.2	35.7
	15/ 7/69	1.0	664	0.6	6.6	52.3
	18/ 8/69	1.0	332	1.6	10.9	119.0
	30/ 9/69	2.0	188	0.5	4.9	98.4
Muskoka (M-2)	28/ 5/69	2.0	730	6.9	68.5	213.5
	25/ 6/69	2.0	374	5.1	53.7	126.2
	16/ 7/69	1.0	466	1.2	11.3	42.9
	21/ 8/69	2.0	605	0.6	5.9	22.2
	30/ 9/69	4.0	188	1.2	14.6	136.6

Table 2.4 Cont'd..

	Date	Depth (m)	Light Intensity (g cal cm^{-2})	mg C m^{-3} hr^{-1}	mg C m^{-3} day^{-1}	mg C m^{-2} day^{-1}
Muskoka (M-3)	29/ 5/69	1.0	391	5.5	55.2	203.8
	25/ 6/69	1.0	374	2.4	23.4	88.4
	16/ 7/69	2.0	466	1.5	13.7	26.7
	20/ 8/69	2.0	615	2.3	21.7	76.3
	2/10/69	2.0	268	0.7	6.0	18.6
<u>BAYS</u>						
Little Joseph (J-8)	28/ 5/69	3.0	730	3.7	37.8	214.2
	26/ 6/69	1.0	-	3.8	11.2	139.9
	14/ 7/69	6.0	686	1.5	14.4	94.5
	19/ 8/69	9.0	607	1.1	9.6	58.7
	1/10/69	2.0	268	0.3	2.7	17.0
	7/ 5/70	2.0	491	1.9	21.6	214.5
	20/ 5/70	3.0	695	1.2	16.9	79.5
	4/ 6/70	4.0	643	0.1	0.7	4.1
	16/ 6/70	4.0	382	0.3	1.8	8.3
	30/ 6/70	3.0	341	0.8	9.1	24.6
	15/ 7/70	2.0	345	0.4	2.5	13.8
	28/ 7/70	2.0	531	3.0	29.6	86.4
	11/ 8/70	2.0	435	0.9	7.2	49.0
	25/ 8/70	8.0	529	4.2	41.0	183.0
	8/ 9/70	5.0	73	0.1	1.0	8.1
	6/10/70	3.0	129	0.3	3.1	17.3
Skeleton (R-6)	27/ 5/69	2.0	340	2.6	25.8	128.1
	27/ 6/69	1.0	538	1.9	19.0	81.9
	15/ 7/69	2.0	664	2.7	25.9	148.9
	18/ 8/69	6.0	332	1.0	11.4	79.3
	30/ 9/69	3.0	188	1.6	15.5	70.8

Table 2.4 Cont'd..

	Date	Depth (m)	Light Intensity (g Cal cm^{-2})	mg C m^{-3} hr^{-1}	mg C m^{-3} day^{-1}	mg C m^{-2} day^{-1}
Dudley (M-4)	29/ 5/69	3.0	391	2.9	30.0	138.8
	27/ 6/69	1.0	538	0.8	8.9	39.4
	17/ 7/69	2.0	285	0.7	6.1	15.4
	20/ 8/69	2.0	615	2.7	28.1	51.1
	1/10/69	2.0	268	0.9	10.1	28.6
Gravenhurst (M-1)	28/ 5/69	2.0	730	43.6	420.1	611.3
	24/ 6/69	2.0	310	15.8	156.2	302.5
	16/ 7/69	1.0	466	5.1	49.5	116.5
	21/ 8/69	1.5	605	1.5	15.3	47.5
	29/ 9/69	1.0	214	5.6	54.7	154.8
	6/ 5/70	1.5	741	10.2	107.0	293.4
	21/ 5/70	0.1	602	11.3	101.9	282.6
	3/ 6/70	1.5	524	4.9	46.2	95.3
	17/ 6/70	2.5	435	0.4	3.1	13.7
	23/ 6/70	1.5	683	0.9	8.7	40.7
	24/ 6/70	1.5	660	1.6	14.8	36.2
	25/ 6/70	1.0	503	1.7	15.7	43.8
	26/ 6/70	1.5	621	0.9	7.8	14.7
	27/ 6/70	1.5	581	1.3	12.5	42.8
	28/ 6/70	1.0	549	0.8	8.8	26.8
	29/ 6/70	2.0	74	0.3	2.9	5.2
	30/ 6/70	2.0	341	1.6	17.7	30.1
	1/ 7/70	1.0	438	1.4	16.4	35.7
	2/ 7/70	1.5	541	1.6	18.5	46.1
	16/ 7/70	1.5	435	4.2	22.8	56.0
	24/ 7/70	0.1	470	3.8	26.9	64.6
	29/ 7/70	2.5	617	6.4	60.4	173.5
	13/ 8/70	2.5	480	5.6	49.1	150.1
	27/ 8/70	1.0	514	7.3	84.1	160.6
	2/ 9/70	1.0	509	9.9	108.0	172.7
	10/ 9/70	1.5	153	3.0	32.0	74.8
	7/10/70	6.4	361	6.3	2.9	11.5

Usually, photosynthetic rates were highest following the spring freshet and during the summer periods when blue-green algae were the most important components of the flora. Maximum volumetric rates occurred higher in the water column in Gravenhurst Bay (i.e. approximately 1.3m) than in Lakes Muskoka and Rosseau and Skeleton Bay (i.e. 1.8 - 2.4m) or in Little Joseph and Joseph Lakes (3.8 - 4.0m, respectively).

In general, three types of production depth curves were encountered. First, were those having a single well-defined production maximum in the upper epilimnion with a rapid decline to a compensation depth approximating 3-6m (i.e. Gravenhurst Bay). Similar production-depth curves characterized the waters of Lake Muskoka and Dudley Bay; however, the compensation point extended deeper into the epilimnion than in Gravenhurst Bay, or occasionally into the upper thermocline. Second, were assimilation distributions for Lakes Rosseau and Joseph which were usually orthograde in nature with light inhibition occurring in the near-surface waters and no pronounced depth of optimal photosynthesis. Third, were those for Skeleton Bay and Little Lake Joseph which were often characterized by a production-depth curve having two peaks - one near the surface and another in the thermocline or upper portion of the hypolimnion. For examples of each type refer to Figures 2.3 and 2.4.

DISCUSSION

As indicated earlier, a bimodal pattern of phytoplankton development with spring and fall maxima occurred at stations located in Lake Muskoka, Dudley and Skeleton Bays and Little Lake Joseph while in Lakes Rosseau and Joseph only fall maxima were detected. In Gravenhurst Bay, spring maxima developed in both years and high levels continued into the early summer months. Davis (1964) and Michalski (1968a) reporting on phytoplankton stocks in Lake Erie, indicated that an increase in the intensity and duration of the spring maximum clearly depicted accelerated enrichment in the lake. As mentioned above, a similar pattern characterized phytoplankton conditions in Gravenhurst Bay during the ice-free periods of 1969 and 1970, thus reflecting the enriched nature of the Bay.

Table 2.5 provides for comparative purposes a breakdown of phytoplanktonic conditions from several lakes in Ontario. The data are based on collections of samples approximating the same period in 1969 (i.e. May - September) when sampling was carried out in Gravenhurst Bay, except for Georgian Bay where information was collected near Collingwood. At Collingwood, data were obtained during the ice-free period of 1968; phytoplanktonic conditions in 1969 are assumed similar to those of 1968. It should be emphasized that water from the Collingwood and Grand Bend areas may be more typical of general water quality throughout Georgian Bay and Lake Huron, respectively. As indicated, standing stocks of algae at all stations except for those of Gravenhurst Bay and to a lesser extent those of Skeleton Bay were slightly higher than those of Collingwood, Grand Bend and Hamilton (municipalities located on the shorelines of oligotrophic to mesotrophic waters), yet significantly lower than those recorded for the Union Water Treatment Plant, Dows Lake, Riley Lake and Penetang Harbour - four extremely enriched bodies of water. Significantly, phytoplankton populations in Gravenhurst Bay were of the same order of magnitude as those recorded from the Union Plant, Dows Lake, Riley Lake and Penetang Harbour. The relatively high phytoplankton stocks for Skeleton Bay might be expected owing to natural inputs of nutrients from the Bay's relatively large watershed (142.5 km^2).

Table 2.5: Summary of phytoplanktonic data collected from various sources during the summer of 1969, except for the Collingwood information which was obtained during the ice-free period of 1968. All results are expressed in areal standard units per millilitre.

Municipality	Source	Number of Samples	Areal Standard Units ml^{-1} Range	Mean	Trophic Status
-	Lake Joseph	21	31-1,153	402	Oligotrophic
-	Lake Rosseau	22	54-1,880	479	Oligotrophic
-	Lake Muskoka	45	98-1,469	510	Oligotrophic to Mesotrophic
-	Little Lake Joseph	23	187-1,945	733	Oligotrophic
-	Skeleton Bay	22	200-1,869	890	Oligotrophic
-	Dudley Bay	22	260-1,285	646	Oligotrophic to Mesotrophic
-	Gravenhurst Bay	25	134-6,402	2,686	Eutrophic
-	Riley Lake	72	141-5,056	1,912	Eutrophic
Ottawa	Dows Lake	20	455-13,651	5,581	Eutrophic
Penetanguishene	Penetang Bay	36	281- 9,577	2,510	Eutrophic
Kingsville Union	Lake Erie Western Basin	26	1,022- 7,147	3,190	Eutrophic
Collingwood	Georgian Bay	207	7- 708	226	Oligotrophic
Grand Bend	Lake Huron	25	23- 559	155	Oligotrophic
Hamilton	Lake Ontario	26	128- 1,313	276	Oligotrophic - mesotrophic

The following comments relate to the ecology of the most important algal types observed in the Muskoka Lakes. At present, a good deal of conjecture exists with respect to the ecological niche for A. formosa, the most ubiquitous of diatoms encountered in the study area. In European lakes and in some North American waters, this species is associated with eutrophic conditions. For example, its incidence in Lake Windermere in the English Lake District was a result of human disturbances of the basin (Pennington 1943). Patrick and Reimer (1966) describe this species as "planktonic.......most often found in mesotrophic waters." On the other hand, Rawson (1956) reported that A. formosa is a characteristically oligotrophic organism in large Canadian lakes. Data presented in this study indicates this species is common to the flora of many inland Ontario lakes, generally dominating during the spring seasons. As suggested by Stoermer and Yang (1970) and Veal and Michalski (1971), it is possible that A. formosa occupies a broad ecological niche, and that it may include a large number of sub-species and physiological strains which are not morphologically distinguishable. Reference to the study area suggests a preference for enriched waters.

The relative abundance of T. fenestrata outside the thermal bar of Lake Michigan was believed to be related to lower nutrient conditions characteristic in offshore waters (Stoermer 1968). Lundh (1951) in his investigations of algae and aquatic macrophytes in the Scanian Lakes found that one of the most frequent dominants in lakes situated on archean bedrock (similar to Precambrian Shield lakes in Ontario) was T. fenestrata. The exclusion of this species from Gravenhurst Bay indicates that nutrient-poor conditions prevail outside the geographical limits of the Bay. R. eriensis, a small transparent diatom,is frequently associated with oligotrophic waters; for example, it is an important component of the flora of Lake Superior (Putnam and Olson 1961) and is common in the off-shore waters of Lake Michigan, Holland and Beeton (1972). Hohn (1969) pointed out that this species has declined to insignificance over the past 30 years in the Bass Islands Area of Lake Erie. Significantly, R. eriensis was observed in samples secured only from the unproductive waters of the system (i.e. all stations except for Gravenhurst Bay). Numerous algologists including Rodhe, Vollenweider and Nauwerck 1958, Nalwajko 1962, Hutchinson 1967, Vollenweider and Saraceni 1964, and Stockner and Benson

1967 associate F. crotonensis with eutrophic conditions. The declining importance of F. crotenensis from Gravenhurst Bay where this species was the most abundant diatom during the summer months, to Lake Muskoka where moderately high numbers were found during July and August to Lakes Rosseau, Joseph and Little Joseph where only rare sightings occurred, is an indication that conditions of accelerated enrichment are presently developing in Muskoka Lake. As pointed out earlier, C. stelligera was present at all sampling sites although greater numbers occurred in Gravenhurst Bay than elsewhere - a development which is somewhat surprising in light of the current literature. For example, Holland and Beeton (1972) indicated that C. stelligera usually favours waters having a combination of low nutrient conditions and relatively high temperatures, although Schelske, Callender and Stoermer (as quoted by Holland and Beeton 1972) found that increases in C. stelligera in field polythylene bag studies were related to silica additions rather than to enrichment with phosphorus and nitrogen.

In general, C. hirundinella - the most important dinophyte encountered during the two years of study - can be found in waters ranging between oligotrophy and eutrophy. However, data collected from the Muskoka Lakes indicate a definite preference for a highly enriched habitat as excessively high numbers materialized in Gravenhurst Bay; elsewhere sightings for C. hirundinella were rare.

The development of many species of chrysophytes during the late spring and early summer months in nutrient-deficient lakes of the Precambrian Shield is common. For example, Schindler and Nighswander (1970) and Schindler and Holmgren (1971) point out that chrysophycean species constituted a high proportion of the total biomass in Clear Lake in Sherborne Township of Haliburton County and in the E.L.A. (Experimental Lakes Area) lakes near Kenora. The preponderance of D. bavaricum, D. sertularia, S. uvella and Mallomonas spp. at all locations except for Gravenhurst Bay is in keeping with our expectations concerning the ecological requirements for these species in lakes of Precambrian origin.

As indicated earlier, maximum numbers for the cryptophycean algae R. minuta and C. erosa materialized in Gravenhurst Bay. Limited information relative to the preferences of these algae can be gleaned from the literature. In point of fact, many workers have neglected these forms owing mainly to taxonomic difficulties. However, R. minuta and C. erosa are an essential component of the flora and their importance should not be underestimated. Although we have regularly observed these algae in waters ranging between oligotrophy and eutrophy, higher numbers usually develop in enriched habitats such as, the Western Basin of Lake Erie, Toronto Harbour or Dows Lake near Ottawa. Thus, the development of exceptionally high numbers of R. minuta and C. erosa in the productive waters of Gravenhurst Bay is in keeping with our expectations.

Phytoplanktonic communities dominated by Aphanizomenon flos-aquae and Anabaena spp. - types which formed mid-summer and early fall "water blooms" - are characteristic of eutrophic waters. The excessively high densities in Gravenhurst Bay during the latter part of October in 1969 and throughout the late summer and early fall months of 1970 confirm the enriched nature of Gravenhurst Bay. Elsewhere in the study area, troublesome levels of bloom-forming algae did not materialize, although a relatively high number of chroococcalean blue-green species were observed during August and September. Significantly, these species (including C. limneticus, G. lacustris, A. nidulans, A. gelatinosa, A. clathrata, A. elachista and M. tennuissma) are common to the flora of unenriched lakes of the Shield (see Michalski and Robinson 1969, Michalski 1971, Schindler and Nighswander 1970, and Schindler and Holmgren 1971).

The term diversity can be defined as a measure of the number of species (Hooper 1969). High diversity populations are characterized by many kinds of animals or plants; in low diversity situations there is a limitation to a few species. The intensity of one or more environmental factors tends to limit the numbers of species and thereby lowers the diversity. Young (1956) and Margalef (1961) have indicated that increases in nutrient supply may effect a decrease in diversity. Similarly, in the Muskoka system diversity of phytoplankton appears to be reduced as a consequence of man-made nutrient additions to Gravenhurst Bay (see Table 2.3).

Elster (1954) pointed out that the photosynthetic capacity of a lake appeared to be an excellent criterion for establishing an absolute scale for comparing the trophic status between lakes (Table 2.6). However, a number of problems associated primarily with methodology reduce the value of absolute measurements of production (see Vollenweider 1968). In considering Table 2.6, we have attempted to present data acquired using uniform techniques; in some cases, correction factors have been applied; for example, errors resulting from self-absorption when using toluene fluors. In general, maximum volumetric and integrated daily rates for the Muskoka Lakes were slightly lower than those computed for lakes studied in the Experimental Lakes Area near Kenora. (Schindler and Holmgren 1971), were similar or of less magnitude than those determined for Dunlop Lake near Elliot Lake, and were substantially lower than rates determined for Clear Lake - a small 88.4 ha lake located in Sherborne Township of Haliburton (Schindler and Nighswander 1970). Schindler and Nighswander indicated that the unusually high production rates for Clear Lake related partly to the high correction factors applied for filtration error and in part of the highly transparent nature of the lake. Significantly, production rates at each of the eight sampling stations were substantially higher than those measured for Quirke and Pecors Lakes - located near Elliot Lake and affected by pollution from acid-uranium processing wastes. Winberg (1963) proposed four trophic levels based on gross primary production rates for the Byelorussian and Karelian lakes in Russia. The most highly productive or polyeutrophic lakes were those characterized by production rates of 2,800 - 3,750 mg C m^{-2} day $^{-1}$ and higher. His second grouping included relatively shallow, homothermal lakes having "....a rich development of phytoplankton and belonging to the most usual type of eutrophic lakes which are situated in the midst of a cultivated landscape .....with primary production rates approximating 925 - 2,800 mg C m^{-2} day $^{-1}$". Winberg's (1963) clear oligotrophic to mesotrophic waters were those having productivity rates ranging between 375 and 925 mg C m^{-2} day $^{-1}$ while his fourth group included shallow, swampy lakes with low pH, sparse phytoplankton stocks and a rate of photosynthesis approximating 200 - 300 mg C m^{-2} day $^{-1}$. The Muskoka Lakes would be included in Winberg's third classification; as such, the most productive Canadian Shield lakes are, at best, mesotrophic in status. Certainly, the Muskoka Lakes with mid-summer production rates often less than 100 mg C m^{-2} day $^{-1}$ would be classified among the world's least productive lakes.

Table 2.6: Comparison of maximum production rates for several lakes of Precambrian origin with those measured in the Muskoka Lakes System.

Lake	Maximum mg C m^{-3} day^{-1}	Maximum mg C m^{-2} day^{-1}	Investigator
Eastern Great Bear L.	1.0	50.1	Schindler and Holmgren (1971)
McLeod Bay - Great Slave L.	2.0	100.0	" "
Eastern Lake Winnipeg	30.0	50.0	" "
E.L.A. #120	20.0	100.0	" "
E.L.A. #132	150.0	560.0	" "
E.L.A. #230	150.0	930.0	" "
E.L.A. #81	400.0	480.0	" "
E.L.A. #99	2142.0	1500.0	" "
Clear L.	260.0	2570.0	Schindler and Nighswander (1970)
Dunlop L.	30	130	Johnson *et al.* (1970)
Quirke L.	9	70	" "
Pecors L.	4.0	33.0	" "
Joseph L.	18.1	125.0	Present study
Rosseau L.	20.2	119.0	" "
Muskoka L.	68.5	203.8	" "
Little Joseph L.	37.8	214.5	" "
Skeleton Bay	25.9	148.9	" "
Dudley Bay	30.0	128.8	" "
Gravenhurst Bay	420.1	611.3	" "

Recently, Vallentyne (1969) pointed out that primary productivity measured as mg C m^{-2} day $^{-1}$" ....was considered of much lower significance in relation to human use of water. This is because of the tendency for clear waters with low phytoplankton concentrations and few eutrophication problems to yield relatively high production values when integrated over depth." The author proposed 0.20 - 0.40 mg C l^{-1} day $^{-1}$ as guidelines which demarcate acceptable (oligotrophic) and dangerous (eutrophic) levels. Applying Vallentyne's guidelines to our study area, dangerous levels were reported only from Gravenhurst Bay (i.e. 0.42 mg C l^{-1} day $^{-1}$); elsewhere, productivity rates can be considered acceptable or "oligotrophic in magnitude" as maximum values rarely exceeded 0.05 mg C l^{-1} day $^{-1}$.

Findenegg (1964) pointed out that the characteristics of the vertical carbon assimilation curve often provide a better indication of the trophic nature of a lake than do integrated daily yields or annual yields. The author considered that, "....the shape of the vertical assimilation curve is very much more informative with regard to the degree of eutrophication than is the amount of organic matter produced per surface unit." The main types of distribution encountered in the study area closely resemble the three major types identified by Findenegg and warrant further comment. Findenegg's Type I curve was characteristic of lakes having a near-surface maximum and a decrease in productivity with depth corresponding to the exponential decrease in light. Also, this curve was associated with lakes rich in phytoplankton and having "....all other qualities characteristic of eutrophic lakes." Gravenhurst Bay best exemplifies Findenegg's Type I class. Stations located in Lake Muskoka (M-2 and M-3) and Dudley Bay (M-4) also exhibited the Type I production depth curve; however, the compensaion point for these stations extended deeper into the water column than in Gravenhurst Bay. Although, other qualities normally associated with eutrophic waters such as high phyto-plankton stocks, high nutrient levels, poor water clarity and high intergrated rates of production were not typically measured in Lake Muskoka and Dudley Bay, it is our contention that the shapes of the vertical assimilation curves suggest conditions of mesotrophy or early eutrophy for these waters A Type II oligotrophic assimilation distribution was defined as orthograde

or non-diminishing, with light inhibition in the uppermost layer and no pronounced optimal depth of photosynthesis. According to the author, the Type II distribution which generally characterizes the waters of Lakes Joseph and Rosseau reflects a scarcity of nutrients rather than light limiting conditions. However, with respect to our study area, it is difficult to prove conclusively that nutrients are more limiting in Lakes Joseph and Rosseau than elsewhere in the system where equally low concentrations of phosphorus, nitrogen, silica and carbon were measured (except of course, for Gravenhurst Bay). In addition to a single epilimnetic maximum, the Type III or mesotrophic distribution is characterized by a second production peak, usually occurring in the metalimnion. During the late summer, "....the metalimnetic production can be as high and it sometimes exceeds that of the epilimnion. So it is not astonishing that this assimilation type seems to produce more than the others and even more than does Type I, which is characteristic for typical eutrophic lakes." European lakes exhibiting the Type III distribution are usually those affected by cultural eutrophication and have metalimnetic pulses of <u>Oscillatoria rubescens</u> (Ravera and Vollenweider 1968). As indicated earlier, Little Lake Joseph and Skeleton Bay exhibited the Type III distribution during the summer months and, on the basis of Findenegg's classification should be considered as mesotrophic. However, these waters are not, at this point in time, "culturally enriched" to any degree. Schindler and Holmgren (1971) regularly encountered the Type III production depth curves in waters of the Experimental Lakes Area and considered that "....the upper production maximum was probably due to optimum light conditions even though nutrients were relatively scarce; the lower maximum was the result of a more favorable nutrient regime (N, P, CO_2), which is an effective stimulant even at low light intensities. This type is undoubtedly characteristic of all lakes with a euphotic zone extending into a metalimnion or hypolimnion rich in nutrients". As pointed out earlier (see Chapter 1), the euphotic zone in Little Lake Joseph extended well into the hypolimnion and approximated the lower limit of the thermocline in Skeleton Bay. Thus, one must be extremely cautious when developing cause and effect relationships associated with the Type III distribution.

CHAPTER 3

CRUSTACEAN PLANKTON COMMUNITIES
AT THREE LOCATIONS
IN THE MUSKOKA LAKES

CHAPTER 3 - CRUSTACEAN PLANKTON COMMUNITIES AT THREE LOCATIONS IN THE MUSKOKA LAKES

INTRODUCTION

Few data are currently available on zooplankton conditions in Ontario's Precambrian Shield and virtually no published works exist on crustacean plankton populations of the Muskoka Lakes. This chapter presents information on zooplankton densities, seasonal successions and community structure during the ice-free period of 1969 in Gravenhurst Bay, Lake Joseph and Little Lake Joseph and considers these findings in assessing trophic conditions. Additionally, it is suggested that the data will be important for use as base-line information for future comparisons of water quality.

METHODS

Field methods

Plankton samples were obtained from five depths at each station using a 4-litre Van Dorn Water sampler. In addition to samples taken at depths of 1m and 2m above bottom, collections were made immediately above and below the thermocline and from a depth mid-way between the thermocline and the sediments. Samples were passed through a Number 20 bolting silk (mesh size 74 μ); filtrates were diluted with distilled water, preserved with a 33% formaldehyde solution, and transported to Toronto for analyses.

Laboratory methods

Each sample was emptied into a petri dish and examined (qualitatively and quantitatively) using a dissecting microscope with a 40X maximum magnification. To facilitate identification, a compound microscope

Table 3.1: Crustacean species found at M-1, J-7 and J-8 for the period May 22 to September 24, 1969.

Species	M-1	J-7	J-8
Senecella calanoides Juday		X	X
Epischura lacustris S.A. Forbes		X	X
Diaptomus minutus Lilljeborg	X	X	X
Diaptomus sicilis S.A. Forbes		X	
Diaptomus oregonensis Lilljeborg	X	X	X
Cyclops biscuspidatus thomasi S.A. Forbes	X	X	X
Mesocyclops edax S.A. Forbes	X	X	X
Cyclops scutifer Sars			X
Polyphemus pediculus Linne	X	X	X
Sida crystallina O.F. Mueller		X	X
Holopedium gibberum Zaddach		X	X
Diaphanosoma leuchtenbergianum Fischer	X	X	X
Daphnia sp.	X	X	X
Daphnia ambigua Scourfield	X		
Daphnia longiremis Sars	X	X	X
Daphnia catawba Coker		X	
Daphnia retrocurva Forbes	X		X
Daphnia galeata mendotae Birge	X	X	X
Bosmina spp.	X	X	X

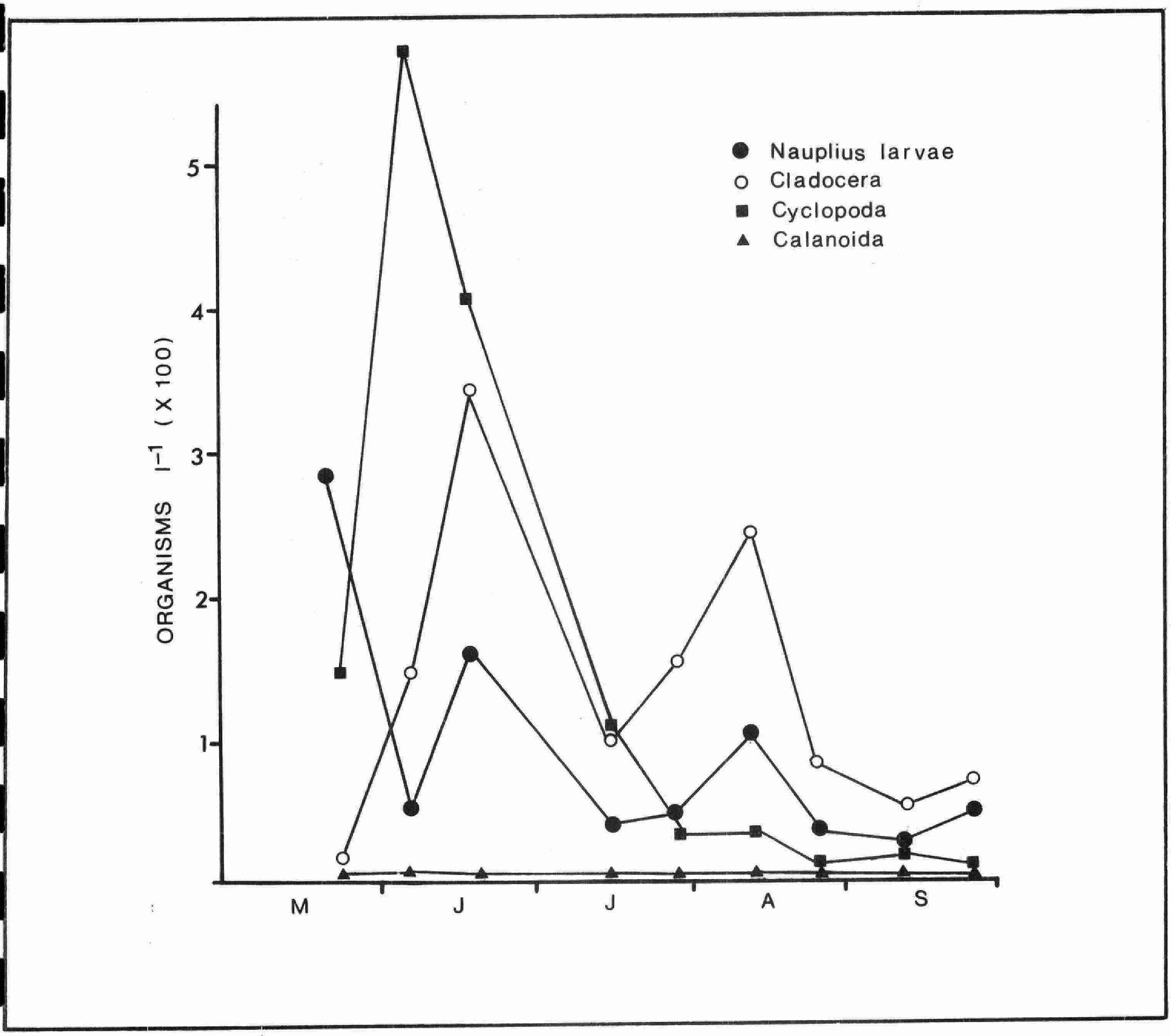

Figure 3.1a: Seasonal changes in relative abundance of zooplankton populations at Station M-1 in Gravenhurst Bay for the sampling period May 22 to September 24, 1969.

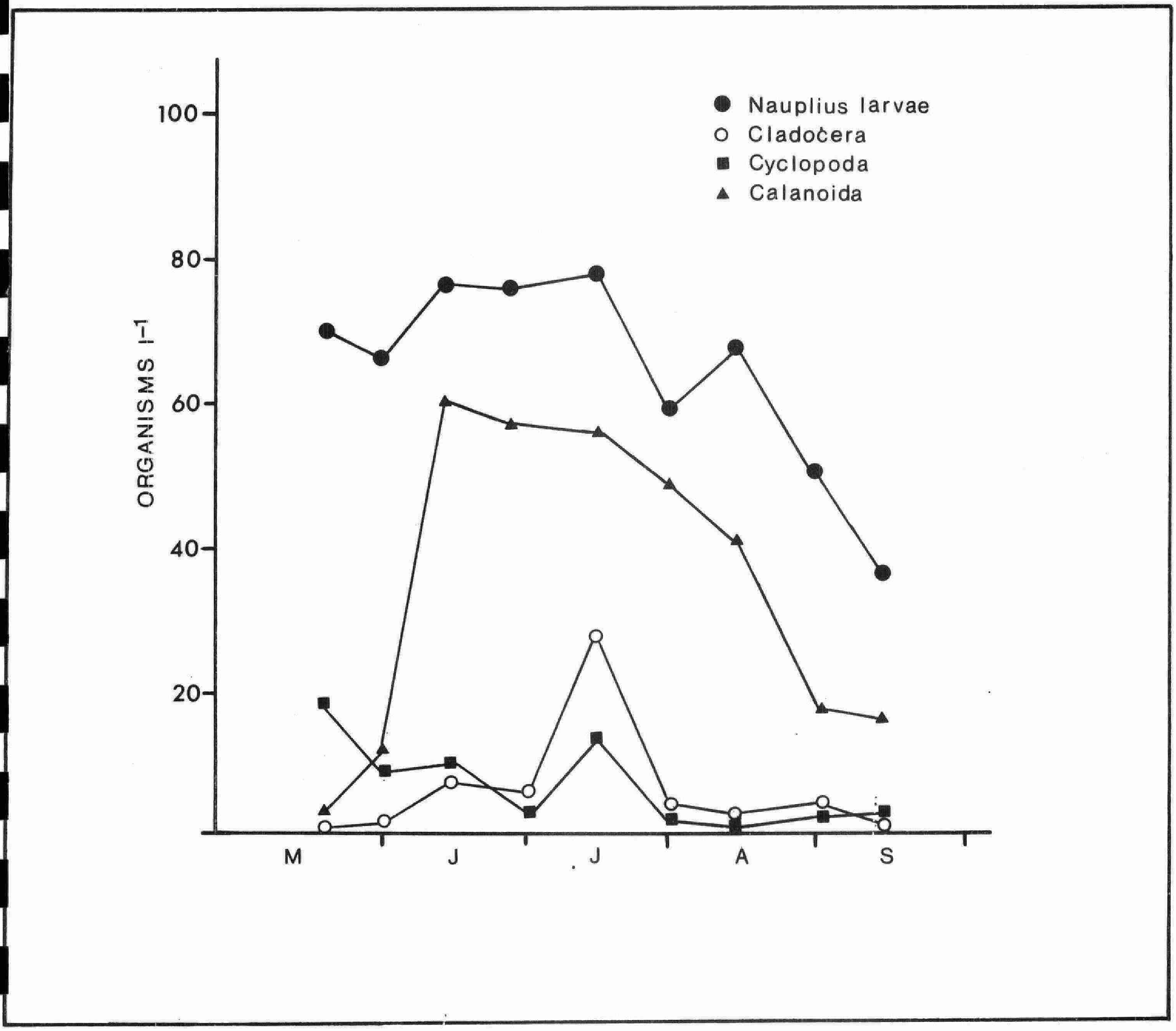

Figure 3.1b: Seasonal changes in relative abundance of zooplankton populations at Station J-7 in Lake Joseph during the period May 23 to September 9, 1969.

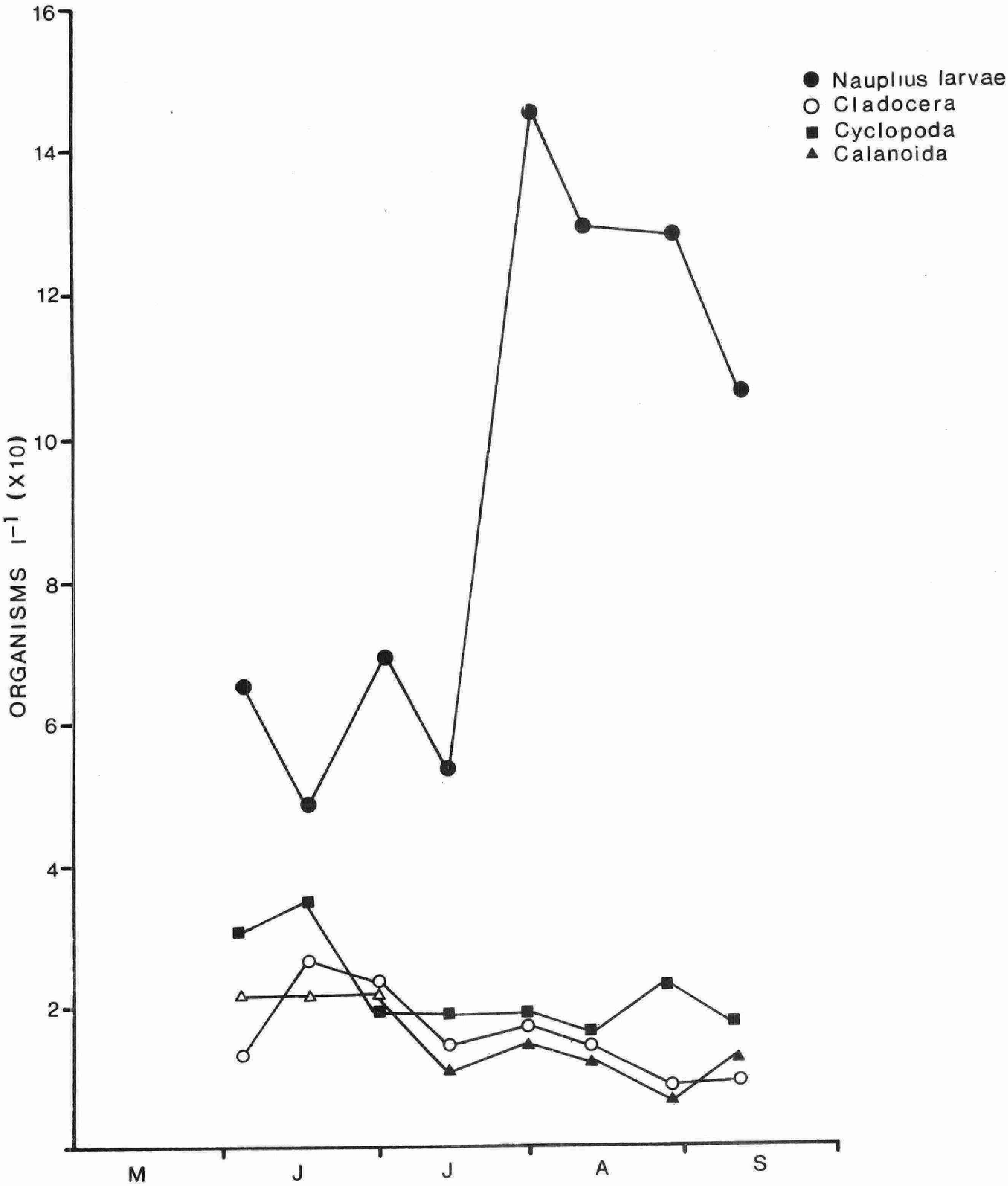

Figure 3.1c: Seasonal changes in relative abundance of zooplankton populations at Station J-8 in Little Lake Joseph for the sampling period June 3 to September 9, 1969.

proved useful for clarifying the more detailed taxonomic features. For some of the Gravenhurst Bay samples, it was necessary to sub-sample the original collection. This was accomplished by diluting the original samples to 30ml, mixing and acquiring an aliquot of 5ml from the middle of the sample using a wide-mouthed volumetric pipette. Taxonomic references consulted included Edmondson (1959), Brooks (1957) and Czaika and Robertson (1968).

RESULTS

Species composition and seasonal succession

Table 3.1 provides a breakdown of species identified at stations located in Gravenhurst Bay (M-1), Little Lake Joseph (J-8) and Lake Joseph (J-7) for the period May 22 to September 24, 1969. In all, seventeen species of crustaceans were confirmed - 5 calanoids, 3 cyclopoids and 9 cladocerans.

Figures 3.1a, b and c depict changes in standing stocks of zooplankton for the aforementioned period. The line graphs in the Figures should not be interpolated to true densities of zooplankton through the water column as each entry on the graph was derived from only five sampling depths.

Considering the three sampling sites, highest numbers of calanoids (0-29 organisms l^{-1}) occurred in Lake Joseph (Figure 3.1b) with lower numbers (0-13 organisms l^{-1}) developing in Little Lake Joseph (Figure 3.1c). Representatives from the calanoid grouping were either absent or present in extremely low numbers in Gravenhurst Bay (Figure 3.1a). Diaptomus minutus was the most important species encountered at Stations J-7 and J-8 although Senecella calanoides, Epischura lacustris, Diaptomus oregonensis and Diaptomus sicilis were regularly encountered.

Higher numbers of cladocerans were found at M-1 than at J-7 or J-8. Daphnia galeata mendotae was the dominant cladoceran encountered in Gravenhurst Bay, attaining numbers in excess of 100 organisms per litre during the mid-June period. Additionally, at M-1 only, a form of Bosmina coregoni coregoni,

in which the mucro(homologous with the shell spine in *Daphnia*)was absent, was regularly observed throughout the sampling period. Highest numbers (155 organisms l^{-1}) for this plankter occurred during the middle of August. At Stations J-7 and J-8, numbers of cladocerans were an order of magnitude lower (i.e. 0-26 organisms l^{-1}). In contrast to Gravenhurst Bay where *D.galeata mendotae* was the most important species, several plankters alternated dominancy at J-7 and J-8. The most frequently encountered form was *Bosmina* sp; this plankter never exceeded 5 organisms l^{-1}. *Holopedium gibberum*, *Daphnia longiremis* and *Sida crystallina* occurred irregularly in the assemblages of J-7 and J-8, but were never encountered in Gravenhurst Bay. Neither species reached high densities, although on July 15 at 64m in Lake Joseph, *S. crystallina* attained a maximum of 16.0 organisms per litre (see Appendix D).

Representatives of the cyclopoid grouping included *Cyclops biscuspidatus thomasi* and *Mesocyclops edax*, although *Cyclops scutifer* was observed on one occasion in Little Lake Joseph. Higher numbers of cyclopoids occurred in Gravenhurst Bay with *C.bicuspidatus thomasi* attaining a level of 289 organisms l^{-1} on June 6.

Vertical distributions of zooplankton populations

Figure 3.2a, b and c defines the vertical distribution of crustaceans at Stations M-1, J-7 and J-8, respectively; depths of the metalimnion, Secchi disc levels and mean dissolved oxygen concentrations in the hypolimnia are also presented. In Gravenhurst Bay, maximum numbers of crustaceans materialized immediately above the metalimnion. On dates following June 19, dissolved oxygen conditions less than 3 mg l^{-1} characterized most of the metalimnial region and all of the hypolimnion.

In Lake Joseph, maximum numbers were encountered in the upper layers of the epilimnion during the late spring and early summer months; thereafter, highest numbers were found in the lower portion of the thermocline or in the upper hypolimnial region.

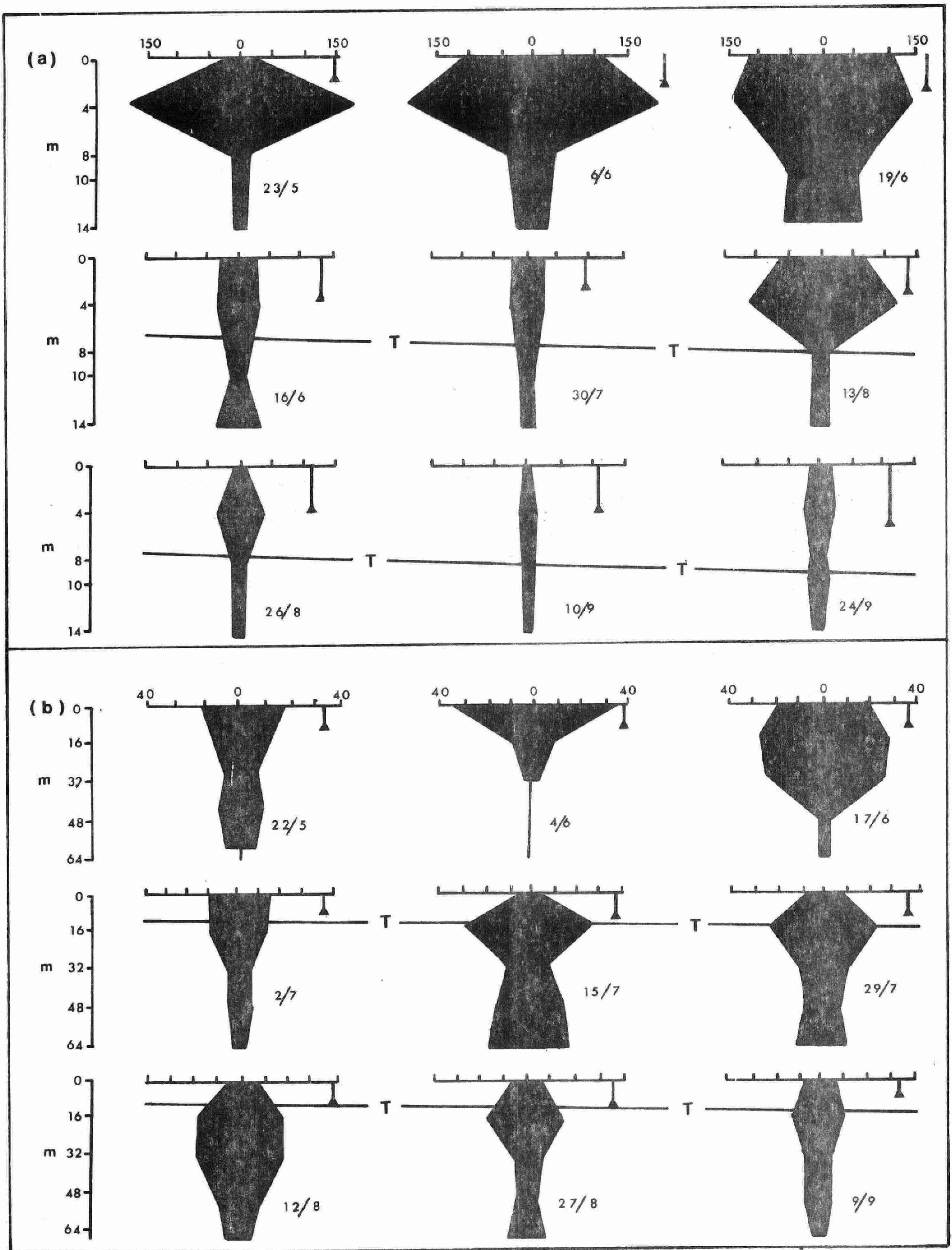

Figure 3.2: Vertical distribution of zooplankton in Gravehurst Bay (a) and Lake Joseph (b) on nine sampling occasions in the summer of 1969. Approximate Secchi disc values and positions of the thermocline are presented. Quantities are as organisms l^{-1}.

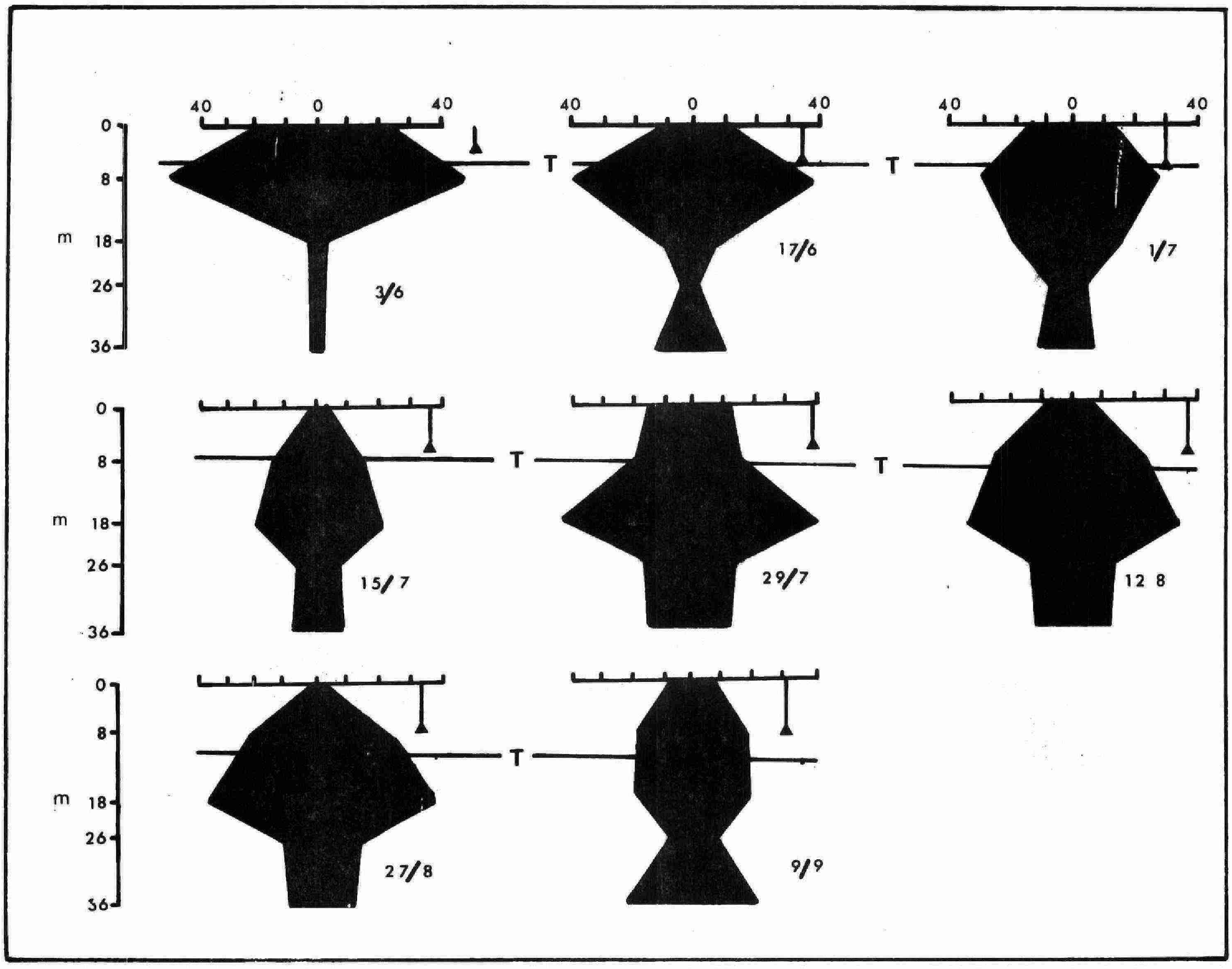

Figure 3.2c: Vertical distribution of zooplankton in Little Lake Joseph on eight sampling occasions in the summer of 1969. Approximate Secchi disc values and positions of the thermocline are presented. Quantities are as organisms l^{-1}.

In Little Lake Joseph, maximum crustacean populations for the first three sampling dates were at 8m of depth - a strata of water representing a zone immediately below the metalimnion. As the season progressed, highest numbers were found lower in the water column, yet still in the zone of water approximating the upper hypolimnion. For example, on August 27, densities of zooplankton were highest at 18m of depth. Preferences for the meta-hypolimnial regions reflects the presence of adequate food and suitable temperature and oxygen regimes (see Chapters 1.1 and 1.2).

DISCUSSION

Zooplankton form a critical link in the aquatic food chain. With few exceptions (such as Cyclops spp. which are given to seizing small animals), zooplankton can be considered as planktonic herbivores that concentrate, filter and assimilate fine particles - algae, bacteria, detritus - suspended in the surrounding medium. In turn, these zooplankters are fed upon by many freshwater fish, although other non-planktonic food sources may be utilized (small fish and benthic invertebrates). Inter-relationships between the three trophic levels - phytoplankton, zooplankton and fish - play an important role in the dynamics of zooplankton populations. For example, large crustaceans are capable of filtering both large and small food particles, at the expense of smaller species. On the other hand, predation reduces the larger forms (for example, trout grazing on daphnids); subsequently the smaller zooplankton proliferate. As a consequence interpretation of standing stocks of zooplankton in light of composition, seasonal and spatial changes are often difficult, especially when utilizing the data to assess the trophic status of a lake. Nonetheless, certain inherent changes may accompany conditions of accelerated eutrophy. For example, Patalas (1971b) has noted that three principle changes occur at the community level with increasing enrichment. First, certain species disappear; second, other species appear and third, changes in the relative abundance of certain species may occur.

As a second example, Schindler and Novén (1971) stated that, "...the effects of eutrophication upon the zooplankton community if viewed in the broadest sense, should be twofold: (1) increases in the biomass and production of zooplankton in response to changes in phytoplankton production and phytoplankton species composition; (2) changes in the species composition of zooplankton due to changes in food quantity and quality." Thus, the high standing stocks in Gravenhurst Bay are undoubtedly related to the increased food potential of the Bay - a condition determined by artificial inputs of algal-growth stimulating nutrients. On the other hand, the relatively low crustacean densities of Lake Joseph reflect a nutrient-deficient or oligotrophic environment. Because S. calanoides, D. sicilis and E. lacustris were not encountered in Gravenhurst Bay but were present in Lakes Joseph and Little Joseph, one might expect to associate these species with unenriched habitats. However, Patalas (1971b) reported the former two species only from large, deep lakes in the Experimental Lake Area near Kenora, Ontario, while the latter form, although ubiquitous to many lake systems, preferred clear, deep-water lakes. Gravenhurst Bay by virtue of its shallow nature (i.e. 14m) would not be expected to harbour these species. Thus, lake morphometry appears to be more important in regulating species design for S. calanoides, E. lacurstris and D. sicilis than trophic differences in the Muskoka Lakes.

With respect to zooplanktonic indicators of enrichment, Pejler (1965) considered H. gibberium to reflect oligotrophic soft-water conditions. Significantly, this species was found only in the waters of Lake Joseph and Little Lake Joseph. In a study of Polish Lakes, Patalas and Patalas (1966), found B. coregoni coregoni common to eutrophic lakes; in our study, this species was confined to the waters of Gravenhurst Bay. In the Laurentian Great Lakes, Patalas (1972) noted that characteristic trends in zooplankton communities occur in relation to increasing nutrients. A general trend was observed from oligotrophic Lake Superior to eutrophic Lake Erie i.e. a diminishing significance of calanoides with a corresponding increase in the significance of cyclopoids and cladocerans. As evidenced in our study a similar trend was observed (see Table 3.2). For example, calanoides were poorly represented while cladocerans and cyclopoids were abundant in Gravenhurst Bay. Conversely, calanoid species dominated the oligotrophic waters of Lake Joseph and Little Lake Joseph while cyclopoids and cladocerans were less significant than in Gravenhurst Bay.

It is interesting to determine whether our naturalistic approach which empirically associates various species with a specific trophic level can be validated from a more objective point of view. We employed Jaccard's (1932) co-efficient of community (which has subsequently been used by Patalas 1971b) to determine the extent to which the zooplankton at the three stations were comparable to or differed from each other. Jaccard's relationship is:

$$cc = \frac{100.c}{a + b - c} \quad \text{where}$$

a is the number of species in the first community,

b is the number of species in the second community,

c is the number of species common to both communities and,

cc is a measure of the percentage of species common to two communities.

When two communities have identical species, the co-efficient of community is 100; when the communities are composed of entirely different species, the co-efficient of community is zero. Table 3.3 provides a comparison between the three stations. As indicated Stations J-7 and J-8 exhibited only moderate similarity to Station M-1. In contrast, when compared with each other Stations J-7 and J-8 displayed a high co-efficient of community. One might interpret these data with a view to suggesting that the changes in community structure from the oligotrophic waters of Lake Joseph and Little Lake Joseph to the eutrophic condition of Gravenhurst Bay has materialized as a consequence of nutrient enrichment. However, the low co-efficients of community values between M-1 and J-7 and M-1 and J-8 could reflect community differences resulting solely from basic morphometric differences. For example, Patalas (1971b) stated "....in situations where two lakes of different size and depth were in close proximity and were interconnected with each other, no similarity in their plankton community was observed" and "....within the E.L.A. it appears that lake area and depth are more significant than location." Without sufficient background information documenting the succession of zooplankton populations in Gravenhurst Bay, it is extremely difficult to determine conclusively whether the current standing stocks of zooplankton are a direct consequence of artificial nutrient enrichment. Nonetheless, the existing fauna at the three locations will serve as a useful baseline for future water quality comparisons.

Table 3.2: Percentage composition of crustaceans found at Stations M-1, J-7 and J-8 for the sampling period May 22 to September 24, 1969.

Species	M-1	J-7	J-8
Nauplius larvae	24.7	58.3	64.7
Calanoids	0.8	29.4	14.8
Cyclopoids	42.8	6.5	10.3
Cladocerans	31.7	5.8	10.2

Table 3.3: Comparisons of species composition at Gravenhurst Bay (M-1), Lake Joseph (J-7) and Little Lake Joseph (J-8) for the sampling period May 22 to September 24, 1969, using Jaccard's co-efficient of community.

Station	Co-efficient of Community
M-1 J-7	56
M-1 J-8	61
J-7 J-8	78

CHAPTER 4

BOTTOM FAUNA COMMUNITIES

CHAPTER 4 - BOTTOM FAUNA COMMUNITIES

INTRODUCTION

Part of the Muskoka Lakes study included an investigation of the bottom fauna at the eight sampling areas (see Figure 1.1). The main purpose in studying the bottom fauna was to assist in determining the "trophic status" of each sampling zone. A secondary purpose was to gain further insight into the relationships between bottom fauna communities and other limnological characteristics.

Season concentrations of dissolved oxygen in the profundal region is frequently used in the trophic classification of lakes. Several studies, including the work of Thienemann (1920) which is now over 50 years old, have shown a close relationship between hypolimnetic concentrations of dissolved oxygen and the structure of the profundal benthic community. For this reason, primary attention was paid to this relationship and to the usefulness of employing benthic structure to establish a trophic classification.

METHODS

Each of the eight study areas was sampled twice for benthic macro-invertebrates. The first sampling period lasted from May 6 to June 7, 1969 and the second from July 30 to September 4, 1969.

At each of the four bays (i.e. M-1, M-4, R-6 and J-8), a total of 15 samples was collected during each sampling period; seven dredge samples were collected within 30 meters of the station marker and the remaining eight samples were collected from locations scattered throughout the profundal area of the bay. At the main lake stations (i.e. M-2, M-3, R-5 and J-7), seven samples were collected within 30 meters of the station marker, three from a circle 150 meters from the marker and another three located 300 meters from the marker.

With the exception of J-8, information from the samples collected at the marker (within 30 meters) was used in describing community structure and in drawing relationships to dissolved oxygen. Information from the other stations revealed that the samples collected at the marker were representative of the sampling areas. At J-8, the invertebrate population at the marker was abnormally and unexplainably sparse, unlike the community found at the eight locations spread throughout the bay. For this reason, the bottom fauna discussed at J-8 refers to the samples collected throughout the bay.

All samples were collected using an unmodified Ekman dredge (22.5 x 22.5cm); because of the soft sediment at all eight stations, the dredge was nearly full for practically all hauls. Macroinvertebrates were separated from the sediment using a screen with 0.50mm apertures. The organisms were hand picked and placed in 95% enthanol which was diluted to 70% to 80% with the invertebrate additions.

RESULTS

Density of macroinvertebrates

There is a wide variation of bottom invertebrate abundance throughout the Muskoka Lakes system. Six of the eight sampling locations had similar abundances of invertebrates (averaging spring and late summer results) ranging from 153 m^{-2} to 391 m^{-2} while at M-1 and R-6 there were 5,985 and 3,807 organisms m^{-2}, respectively.

Basic Community Structure

Table 4.1 provides a listing of the invertebrate taxa found at the eight sampling locations.

The following tabulation illustrates the percent composition of the four main groups of organisms.

Figure 4.1: A list of the macroinvertebrates found at each sampling station. With the exception of J-8, the list refers only to animals in samples collected within 30 meters of the station markers.

Species	M-1	M-2	M-3	M-4	R-5	R-6	J-7	J-8
OLIGOCHAETA								
Tubificidae								
Tubifex tubifex	X	X				X		
T.kessleri americanus		X	X	X	X	X	X	X
Limnodrilus hoffmeisteri	X	X	X	X	X	X		X
Rhyacodrilus montana		X	X		X	X	X	X
Ilyodrilus templetoni					X		X	
Naididae								
Arcteonais lomondi				X				
DIPTERA								
Chironomidae								
Chironomus (Chironomus) sp.	X					X	X	X
Chironomus attenuatus	X					X		
C.atritibia						X		
Cryptochironomus digitatus	X							
Procladius sp.	X	X	X	X		X	X	X
Tanytarsus sp.		X		X	X	X	X	
Glyptotendipes sp.							X	
Micropsectra sp.		X	X		X		X	
Phaenopsectra sp.		X	X	X	X	X	X	X
Paracladopelma sp.		X		X				
Heterotrissocladius subpilosus						X	X	
Protanypus spp.				X		X	X	
Stictochironomus sp.								X
Culicidae								
Chaoborus albatus	X			X		X		
Ceratopogonidae								
Palpomyia spp.				X				
Sphaeriidae								
Pisidium conventus		X	X		X		X	X
P.casertanum		X	X	X	X	X	X	X
P.lilljeborgi		X		X			X	
P.aequilaterale							X	
ACARI								
Parasitengone				X		X	X	
NEMATA							X	
CRUSTACEA								
Pontoporeia affinis							X	X

Station	Amphipods (Amphipoda)	Worms (Tubificidae)	Midges (Chironomidae)	Clams (Sphaeriidae)
M-1	0	99	1	0
M-2	0	54	30	16
M-3	0	36	55	9
M-4	0	45	26	28
R-5	0	57	23	20
R-6	0	90	10	<1
J-7	25	28	29	15
J-8	3	23	72	2

Except for J-7 where the amphipod *Pontoporeia affinis* was abundant (also present in small numbers at J-8) three groups of organisms made up practically 100% of the community. At most locations, worms and midges were most abundant, and sphaerid clams rated third. At M-1, and to a lesser degree at R-6, the community was strongly dominated by oligochaetes.

The Worm Structure

Only six species of tubificids were found during the study, one of which (*Aulodrilus americanus*) was not found in the samples collected at the marker and so will be excluded from the discussion. At most of the eight sampling areas, the worm structure was similar with some combination of *Limnodrilus hoffmeisteri*, *Tubifex kessleri americanus*, *Rhyacodrilus montana* and *Ilyodrilus templetoni* dominating.

Dominant Worms*

M-1	*Tubifex tubifex* - *Limnodrilus hoffmeisteri*
M-2	*Limnodrilus hoffmeisteri* - *Tubifex kessleri americanus* *Rhyacodrilus montana*
M-3	As in M-2
M-4	*Limnodrilus hoffmeisteri* - *Tubifex kessleri americanus*
R-5	As in M-4
R-6	As in M-1
J-7	*Rhyacodrilus montana* - *Ilyodrilus templetoni* - *Tubifex kessleri americanus*
J-8	*Tubifex kessleri americanus* - *Ilyodrilus templetoni*

* "Dominant" refers to species that rated first or second in abundance at one or both sampling periods.

At M-1 and R-6, T. tubifex and L. hoffmeisteri, two pollution-tolerant worms, predominated. At M-1, T. tubifex and L. hoffmeisteri were the only two species found and T. tubifex constituted about 95% of the worm population.

The Midge Structure

Eleven genera of the family chironomidae were found. Dominant taxa included Chironomus attenuatus, Procladius spp., Phaenopsectra sp., Micropsectra spp.,* Tanytarsus spp., Chironomus atritibia and Chironomus spp.

Dominant Midges

M-1	Chironomus attenuatus - Procladius spp.
M-2	Phaenopsectra sp. - Micropsectra spp.
M-3	As in M-2
M-4	Phaenopsectra sp. - Tanytarsus spp. Procladius spp.
R-5	As in M-2
R-6	Tanytarsus spp. - Procladius spp. - Chironomus Chironomus spp.
J-7	Phaenopsectra sp. - Micropsectra spp. - Chironomus Chironomus spp. Heterotrissocladius subpilosus
J-8	Chironomus Chironomus spp. - Procladius spp. - Phaenopsectra sp.

Heterotrissocladius subpilosus, which frequently dominates the midge populations of ultra-oligotrophic lakes (Brundin, 1958), was found only at two locations and in very low numbers except for J-7 where it constituted 8% of the midge numbers.

* Most insects were identified to genus; since more than one species can be expected for most genera, the term spp. was used. However, it is recognized that a few genera may contain only one species.

The Clam Structure

Only four species of sphaeriids were found - Pisidium conventus, P. casertanum, P. lilljeborgi and P. aequilaterale. P. conventus and P. casertanum were the only species that were both common and fairly abundant throughout most of the Muskoka system. These two species dominated the clam population in all but the following three areas. At M-1, no clams were found. At R-6, only P. casertanum was recovered and at M-4, P. casertanum and P. lilljeborgi were the only two species collected.

The Amphipod Structure

Locations J-7 and J-8 were the only two areas where the oligotrophic amphipod Pontoporeia affinis was found. At J-7, this species constituted 25% of the total number of organisms.

DISCUSSION

An analysis of benthic community structure has been commonly used by biologists for some time in determining levels of eutrophication and pollution. The profundal benthos seems to be particularily meaningful because it largely reflects the summer and fall concentrations of dissolved oxygen in the hypolimnion. Since the work of Thienemann in 1920, various biologists and limnologists (Brundin 1958, Brinkhurst, Hamilton and Herrington 1968) have provided indications of how benthic communities in lakes can be used to indicate trophic status.

Density of Macroinvertebrate Communities

The macroinvertebrate densities of 153 m^{-2} to 391 m^{-2} at six of the sampling stations illustrate the oligotrophic nature of most of the Muskoka system. Brundin (1958) gives a figure of 300-400 individuals m^{-2} for many of the European oligotrophic lakes. The enriched natures of Gravenhurst and Skeleton Bays are reflected by the much greater densities at these two stations, particularly the former location.

Since the mean bottom temperatures are fairly similar between sampling locations and the basic type of community structure throughout the system is reasonably uniform (i.e. worms, midges and clams), one can assume that benthic production roughly corresponds to density levels. Therefore, the benthic community at M-1 is apparently most productive, R-6 is the second most productive and the remaining areas all have a much lower rate of production.

Worms

Brinkhurst (1967) has suggested that the ratio of L.hoffmeisteri to the total number of worms or to the total number of organisms can serve as a useful indicator of eutrophication. However, these ratios are not meaningful in the present study because in the most enriched area (M-1), T.tubifex rather than L.hoffmeisteri dominates. The authors therefore combined these two species in calculating the ratios (Table 4.1). This revised index, however, could not be applied in cases where T.tubifex is in significant numbers in the unproductive locations as well as the over-productive areas; Brinkhurst (from Brinkhurst, Hamilton and Herrington, 1968) has pointed out that this species is often absent from areas where water quality is between the two extremes.

Trophic levels can also be estimated by investigating dominant species within the oligochaetes. Brinkhurst (1966) has shown that L.hoffmeisteri, while found under a wide variety of conditions, frequently dominates in polluted situations. T.tubifex can be found at both ends of the water quality scale, although in the Muskokas it is found in significant numbers only in the more enriched areas. Also, I.templetoni is confined to the polluted stretches of Lake Ontario, while Rhyacodrilus spp. and T.kessleri americanus are typical of oligotrophic habitats (Brinkhurst, Hamilton and Herrington, 1968). Using this information, plus the authors' experience, one can assume the following.

1) a strong dominance of T.tubifex and L.hoffmeisteri indicates enriched conditions;
2) a strong dominance of T.tubifex over L.hoffmeisteri indicates a greater degree of eutrophy than if L.hoffmeisteri dominates over T.tubifex.

Table 4.2 illustrates the placement of M-1 and R-6 on a trophic scale, based on dominant oligochaete species.

Midges

Thienemann (1920), Brundin (1958) and Hamilton (Brinkhurst, Hamilton and Herrington, 1968) have shown that chironomids are perhaps the most useful group of benthic macroinvertebrates in establishing trophic levels. Thienemann (1920) began classifying lakes by using *Tanytarsus* as an indicator of oligotrophic waters and *Chironomus* as an indicator of eutrophic water. Lenz (1927) and Lundbeck (1936) provided further classification systems based on chironomid communities, and Brundin (1958) suggested five lake types, ranging from the ultra-oligotrophic lake characterized by *Heterotrissocladius subpilosus* to the eutophic lake characterized by *Chironomus*. The *Tanytarsus lugens* and *Stictochironomus* - *Sergentia* (*Phaenopsectra*) lakes, indicating moderate oligotrophy fell between the two extremes. More recently, Hamilton (from Brinkhurst, Hamilton and Herrington, 1968) has shown that *H. subpilosus* and *Chironomus plumosus* communities also can be used to classify various parts of the Great Lakes. In the Muskoka Lakes, the apparent absence of *C. plumosus* even at M-1 indicates that either conditions are not sufficiently eutrophic for this species, or more likely, that *C. attenuatus* replaces *C. plumosus* in these eutrophic waters, perhaps because of their soft-water character. On the other extreme, *H. subpilosus*, which was found at four of the eight locations, did not dominate the midge community, indicating that no part of the system can be called "ultra-oligotrophic". Throughout most of the Muskokas, *Micropsectra* spp. and *Phaenopsectra* sp. dominate the midge population which would place the Muskoka Lakes proper into Brundin's (1958) moderately oligotrophic "*Tanytarsus lugens*" classification. Gravenhurst Bay however, falls into the eutrophic classification as *C. attenuatus* and *Procladius* spp. dominate.

Based on the information of Thienemann (1920) Brundin (1958) and Hamilton (from Brinkhurst, Hamilton and Herrington 1968) plus the authors' personal experience, the following scale of midge dominance was used in rating the relative trophic nature of the eight sampling areas:

Table 4.2: Levels of eutrophy suggested by various indices and community structures compared with the trophic level suggested by minimum levels of dissolved oxygen (1969 data).

ultra-eutrophic	$\frac{L.hoffmeisteri + T.tubifex}{\text{Total \# worms}} \times 100$	$\frac{L.hoffmeisteri + T.tubifex}{\text{Total \# organisms}} \times 100$	Dominant Worms	Dominant Midges	Dominant Clams	Ave. Trophic Rating based on Benthic Community Structure	Trophic Rating based on Minimum Dissolved Oxygen in Bottom waters
eutrophic	M-1 (100)	M-1 (99)	M-1	M-1	M-1	M-1	M-1 (0.2 mg l^{-1})
mesotrophic	R-6 (97)	R-6 (87)	R-6	R-6	R-6	R-6	R-6 (1.7)
	M-4 (87)	M-2 (45)	M-2, R-5	J-8	M-4	M-4	M-4 (2.5)
	M-2 (80)	R-5 (41)	M-4, M-3	M-4	M-2, M-3	M-2	J-8 (5.8)
moderately oligotrophic	M-3 (79)	M-4 (38)	J-8, J-7		R-5, J-7	R-5	M-2 (6.5)
	R-5 (71)	M-3 (29)		M-2, M-3	J-8	M-3	R-5 (6.8)
	J-8 (33)	J-8 (5)		R-5		J-8	M-3 (7.3)
	J-7 (0)	J-7 (0)		J-7		J-7	J-7 (8.6)
ultra oligotrophic							

Chironomus attenuatus - Procladius spp. community more
eutrophic than

Tanytarsus spp. - Procladius spp. - Chironomus Chironomus spp.
more eutrophic than

Chironomus Chironomus spp. - Procladius spp. - Phaenopsectra sp.
more eutrophic than

Phaenopsectra sp. - Tanytarsus spp. - Procladius spp.
more eutrophic than

Phaenopsectra sp. - Micropsectra spp.
more eutrophic than

Phaenopsectra sp. - Micropsectra spp. - Chrionomus Chironomus spp.
Heterotrissocludius subpilosus.

Using this assumption, Table 4.2 illustrates the relative trophic ratings.

Clams

Knowledge on ecological requirements of sphaerids is practically non-existent. However, Herrington (from Brinkhurst, Hamilton and Herrington, 1968) has shown that Pisidium conventus typically dominates in the deeper parts of the oligotrophic Upper Great Lakes. He also found that P. casertanum is common in Lake Erie (including the Western Basin) which perhaps means that this species is more pollution-tolerant than P. conventus. Based on this information, plus the authors' experience, sampling locations were rated according to trophic status assuming:

1) the absence of sphaeriids at M-1 was a result of over-enrichment
2) the absence of P. conventus from R-6 indicated unfavourable conditions for this species and
3) the P. conventus - P. casertanum community indicated more oligotrophic conditions than did the P. casertanum - P. lilljeborgi community.

Table 4.2 illustrates these trophic ratings.

Amphipods

The amphipod order included only one species - Pontoporeia affinis. While its presence in Lake Joseph and Little Lake Joseph demonstrated an oligotrophic or mesotrophic environment, its absence from the other areas does not necessarily suggest less-oligotrophic conditions.

Trophic Classification of Sampling Areas

Table 4.2 illustrates that placement of sampling areas on a trophic scale varies somewhat depending on the rating system used. Because of the inadequacy of sampling which characterizes most studies of this nature, plus the fact that ecological knowledge is at an early stage, it is suggested that the average of a number of indices and techniques be employed to arrive at a final rating. The second last column of Table 4.2 provides a rating based on a summary of the previous five columns. Except for Station J-8, the sequential order of sampling locations is identical to that established by using the criteria of minimum dissolved oxygen in the bottom waters.* This verifies the 50-year-old opinion of Thienemann that profundal macro-invertebrate structure closely reflects the concentration of dissolved oxygen in the bottom waters.

ADDITIONAL COMMENTS

The Muskoka study demonstrated that changes in the bottom fauna of soft-water lakes as a result of eutrophication is not unlike the changes in hard-water lakes. Eutrophy yields the same end result in both cases with Limnodrilus hoffmeisteri, Tubifex tubifex and Chironomus Chironomus dominating the benthic community. The one difference in soft-water lakes may be that Chironomus attenuatus dominates in eutrophic waters rather than Chironomus plumosus.

* "bottom waters" refers to the water 2m above bottom.

The study also revealed that while analyses of benthic communities can be accurately used to establish trophic status, the benthos is fairly similar with respect to both density and structure over a considerable range of dissolved oxygen tensions. While the separation of R-6 and M-1 was not difficult, the trophic rating of the remaining six locations was not clearly defined and the ranking varied depending on the specific index or parameter used. This suggests that providing the bottom waters have a minimum annual dissolved oxygen value of 2.5 mg l^{-1} or more (M-4 had 2.5), the bottom fauna will be indicative of moderately oligotrophic conditions, and the benthos will not be grossly different from that of profundal waters under near saturation oxygen tensions. However, when the level of dissolved oxygen falls below 2 or 2.5 mg l^{-1}, the benthos seem to experience a major shift in both density and species composition.

It is of interest to note that in "clean-water" lakes, the cold-water salmonid fishes may have oxygen requirements not unlike those of the oligotrophic-type bottom fauna. For example, it has been shown in Lake Simcoe that while the minimum hypolimnetic concentrations of dissolved oxygen in the mid-hypolimnion drops to approximately 3 mg l^{-1} (Veal and Clark, 1970),cold-water species (trout, whitefish) show no obvious avoidance reaction to these conditions. It is generally understood that the dissolved oxygen requirements for cold-water species is far greater than 3 mg l^{-1}* and, it may therefore be reasonable to suggest that salmonids would be unable to maintain a population under prolonged dissolved oxygen stresses below 3 mg l^{-1} - perhaps at 2 - 2.5 mg l^{-1}.

Some precautionary notes, however, must be added to the above comments. While the cold-water species in Lake Simcoe tolerate 3 mg l^{-1} dissolved oxygen, it can be assumed that the fish are under stress in

* The OWRC "Guidelines and Criteria for Water Quality Management in Ontario" suggests that dissolved oxygen concentrations should not be below 6 mg l^{-1} for cold-water biota, except for short intervals.

this media and that they prefer values which are near-saturation. Secondly, the low dissolved oxygen requirements for salmonids are probably applicable only to lakes where other environmental conditions are ideal. Thirdly, in a lake where the hypolimnetic dissolved oxygen values fall below 3 mg l^{-1} year after year, the salmonids would certainly be in danger because of the chances of a year with unusual climatic conditions permitting oxygen levels to reach a critically low level. The established criteria of 6 mg l^{-1}, therefore, still had a sound basis.

Another point of interest is the fact that in most lakes, and this is true for the Muskokas, the late-summer concentrations of dissolved oxygen through the hypolimnia are relatively uniform to the sediments. However, within feet of the mud-water interface, dissolved oxygen drops quite sharply. Therefore, if it is true that oligotrophic-type benthic communities and salmonid fishes have similar oxygen requirements, advancing eutrophication would cause the benthos to shift to a eutrophic-type community (e.g. Limnodrilus hoffmeisteri - Chironomus Chironomus dominance) before a cold-water fishery is affected. This concept is supported by Lake Simcoe where the cold-water fishery remains excellent, although a major shift in the benthos has materialized over the past 40 years (Veal and Clark, 1970). In fact, the existing profundal benthos in Lake Simcoe indicates eutrophy. During our 1970 work on the lake, concentrations of dissolved oxygen through most of the hypolimnion reached a low of 3 mg l^{-1}; however, at two meters above bottom concentrations were substantially lower (i.e. 1.0 - 2.4 mg l^{-1}). The aforementioned clearly indicated that careful analyses of benthic communities of large, deep lakes can be used to predict the stability of a cold-water fishery. Specifically, appropriate management techniques must be initiated to reduce the rate of eutrophication and prolong the life of the cold-water fishery as soon as bottom faunal populations shift from an oligotrophic to an eutrophic-type community. It should be recognized that such a shift might occur well in advance of the development of classical hypolimnetic symptoms of eutrophy.

CHAPTER 5

EFFECTS OF ARTIFICIAL FERTILIZATION ON ENCLOSED PHYTOPLANKTON IN GRAVENHURST BAY AND LAKE JOSEPH

CHAPTER 5: Effects of Artificial Fertilization on Enclosed Phytoplankton in Gravenhurst Bay and Lake Joseph.

INTRODUCTION

Lake and pond fertilization has commonly been used as a successful water management tool for improving fish production (Maciolek 1954 and Winberg and Lyaknovich 1965). Most efforts have included treatments with phosphorus and nitrogen augmented in some instances by organic fertilizers and various salts. The most notable effects have included the development of high standing stocks of phytoplankton; however, temporary inhibition (Fournier 1966) or limited effects (Einsele 1941) have been demonstrated. With respect to Canadian Shield Lakes, Langford (1950) and Smith (1969) concluded that phosphorus was the limiting nutrient in Algonquin Park Lakes (Ontario) and Crecy Lake (New Brunswick), respectively. More recently, Schindler et al. 1971 treated a small unproductive Canadian Shield lake in the Experimental Lakes Area near Kenora, Ontario, at rates of phosphorus (0.34 g m^{-2} $year^{-1}$) and nitrogen (5.0 g m^{-2} $year^{-1}$) similar to those entering the Lower Great Lakes. Most notable changes included an increase in algal stocks, a shift in dominancy from Chrysophyceae to Chlorophyceae and a rapid phosphorus and nitrogen loss via the phytoplankton to the sediments. Additionally, from a series of experiments to measure the responses of phytoplankton to various nutrient regimes, the authors reported that "....phosphorus was required as a primary stimulus for phytoplankton increases in the tubes. Nitrogen or carbon may have caused additional increases in phytoplankton once the phosphorus supply was adequate."

To establish an insight into limiting conditions in terms of assessing the relative importance of the three most "in-vogue" nutrients (i.e. phosphorus, nitrogen and carbon), a series of *in situ* experiments were carried out during the summers of 1969 and 1970 in Gravenhurst Bay and Lake Joseph. It was anticipated that results would provide an insight into predicting the causes and consequences of artificial enrichment and possible remedial measures.

METHODS

Experiment Number 1

Bioassays of possible limiting nutrients were conducted in Gravenhurst Bay (Station M-1) and Lake Joseph (Station J-7) in large polyethylene bags in June and late August of 1969. The responses of phytoplankton stocks, primary production and chlorophyll to increased phosphorus, nitrogen and carbon and combinations of these nutrients were examined.

The polyethylene bags of 0.10mm thickness were 3.2m long, 0.4m wide, contained $0.25m^3$ of water and were set so that as much of the column as possible was located in the zone of water having optimum photosynthetic assimilation characteristics (Figure 5.1). Additions of nutrients (Table 5.1) were made at three-to-five day intervals by adding pre-dissolved chemicals to the tubes and thoroughly mixing the column with a Secchi disc or paddle. Sample collections for water chlorophyll, phytoplankton counts and primary productivity estimates were secured using a Van Dorn water sampler immediately prior to all nutrient additions. For field and laboratory methodology regarding sampling techniques and treatment see Chapters 1 and 2.

Experiment Number 2

In June and August of 1970, bioassay bag studies were carried out at Stations M-1 and J-7 to determine the biological responses to additions of sewage treatment plant effluents. One bag received typical secondary sewage effluent to simulate a phosphorus loading similar to that of western Lake Erie (i.e. 7.0 g P m^{-2} $year^{-1}$) while the second received a similar volume of the above treated with 200 mg l^{-1} $Ca(OH)_2$ to remove phosphorus. A third bag served as control. Phosphorus, nitrogen and BOD_5 for the two sewage types are provided below. Sewage additions and water collections etc. were similar to those outlined under Experiment Number 1.

Type of Sewage Effluent	Total Phosphorus mg l^{-1}	Nitrogen (mg l^{-1})				BOD_5
		Free Ammonia	T.K.N.	NO_3	NO_2	
Secondary Sewage	5.300	7.0	11.0	3.3	.12	7.0
Secondary Sewage + $Ca(OH)_2$	0.220	5.0	6.2	2.0	.10	6.2

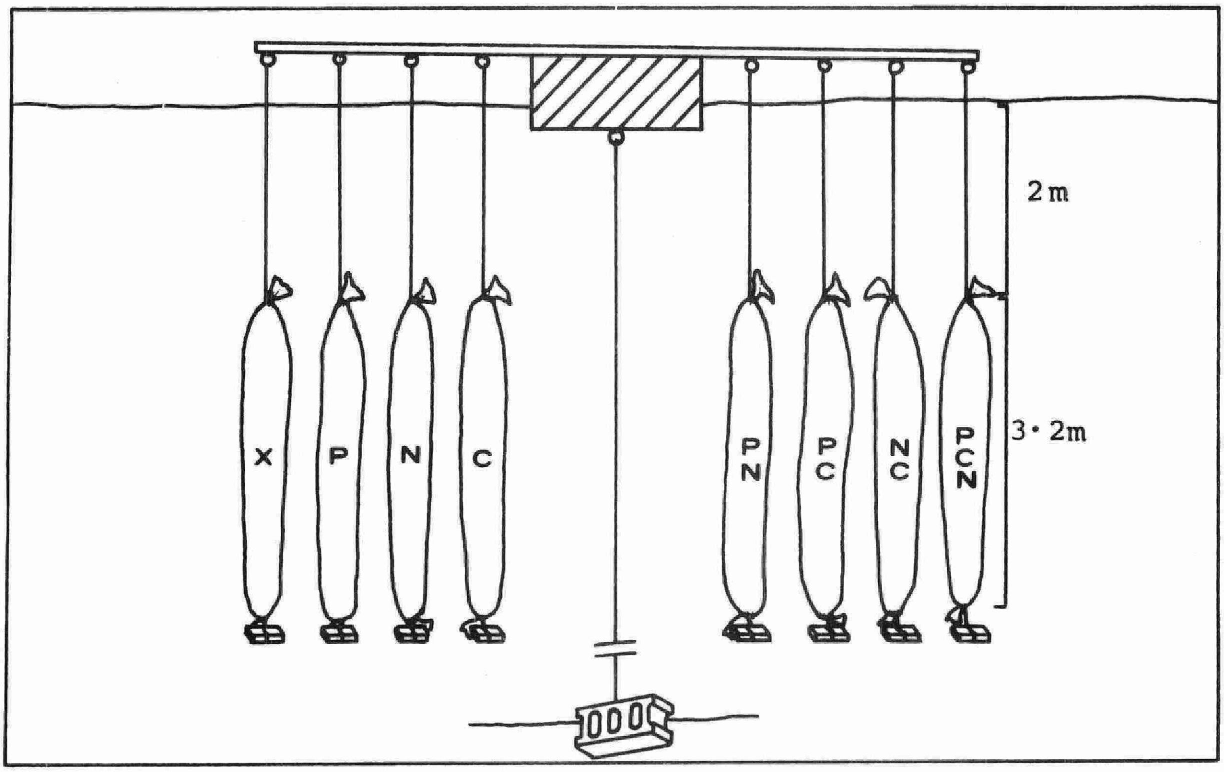

Figure 5.1: Diagrammatic representation used in assessing responses of native phytoplanktonic communities to additions of phosphorus, nitrogen and carbon and combinations of these nutrients to water captured in polyethylene bags. Control bag depicted as "X". Bags hold 0.25 m^3 of water when set.

Table 5.1: Nutrient additions to tubes set in Gravenhurst Bay and Lake Joseph in June and September 1969

Location	Tube Number	Additions
Gravenhurst Bay June 24 and September 29	1	Control
	2	40 µg l^{-1} P as $Na_2 HPO_4.12H_2O$
	3	200 µg l^{-1} N as $NaNO_3$
	4	8 mg l^{-1} C as $NaHCO_3$
	5	40 µg l^{-1} P as $Na_2HPO_4.12H_2O$ + 200 µg l^{-1} N as $NaNO_3$
	6	40 µg l^{-1} P as $Na_2HPO_4.12H_2O$ + 8 mg l^{-1} C as $NaHCO_3$
	7	200 µgl^{-1} N as $NaNO_3$ + 8 mg l^{-1} C as $NaHCO_3$
	8	40 µg l^{-1} P as $Na_2HPO_4.12H_2O$ + 200 µg l^{-1} N as $NaNO_3$ + 8 mg l^{-1} C as $NaHCO_3$
Lake Joseph June 25 and September 29	1	Control
	2	25 µg l^{-1} P as $Na_2HPO_4.12H_2O$
	3	150 µg l^{-1} P as $NaNO_3$
	4	7 mg l^{-1} C as $NaHCO_3$
	5	25 µg l^{-1} P as $Na_2HPO_4.12H_2O$ + 150 µg l^{-1} P as $NaNO_3$
	6	25 µg l^{-1} P as $Na_2HPO_4.12H_2O$ + 7 mg l^{-1} C as $NaHCO_3$
	7	150 µg l^{-1} N as $NaNO_3$ + 7 mg l^{-1} C as $NaHCO_3$
	8	25 µg l^{-1} P as $Na_2HPO_4.12H_2O$ + 150 µg l^{-1} P as $NaNO_3$ + 7 mg l^{-1} C as $NaHCO_3$

Experiment Number 3

An algal assay to determine the effects of mixing the nutrient-rich hypolimnetic waters of Gravenhurst Bay into the overlying epilimnial waters was carried out during the latter part of September and early October 1970. One polyethylene bag containing epilimnion served as a control while a second received 0.10m^3 of water (i.e. approximately 30% hypolimnion) pumped from a depth of 13m. Algal densities, ^{14}C uptake and chemical conditions in both columns were monitored every 1-5 days for a period of 23 days.

DISCUSSION OF RESULTS

Experiment Number 1

Figures 5.2a and 5.2b clearly indicate that positive chlorophyll *a* and phytoplankton responses were detected for all columns receiving nutrient additions. However, highest phytoplankton stocks and chlorophyll *a* concentrations developed in tubes receiving phosphorus - either alone or in combination with nitrogen and carbon. Qualitatively, pre and post-fertilization phytoplankton species were similar; although during the June experiments in Gravenhurst Bay the chlorophycean algae (mainly *Sphaerocystis schroeteri* and *Chlamydomonas* spp.) were proportionately more abundant in those columns receiving nitrogen and nitrogen and carbon together. A corresponding shift to green algae during the August experiment did not materialize. Well-defined increases in primary production rates were not apparent in the Gravenhurst Bay columns (Figure 5.3); in fact, production rates for both the June and August experiments were highest in control tubes. On the other hand, assimilation rates for Lake Joseph tubes receiving phosphorus, phosphorus and nitrogen, phosphorus and carbon or all three were slightly higher than those measured for columns treated with carbon and nitrogen alone or together (Figure 5.3). The rather inconsistent production results are somewhat surprising - especially in columns where elevated phytoplankton stocks and chlorophyll *a* levels developed. Schindler et *al.* (1971) reported similar findings for Lake 227 in the Experimental

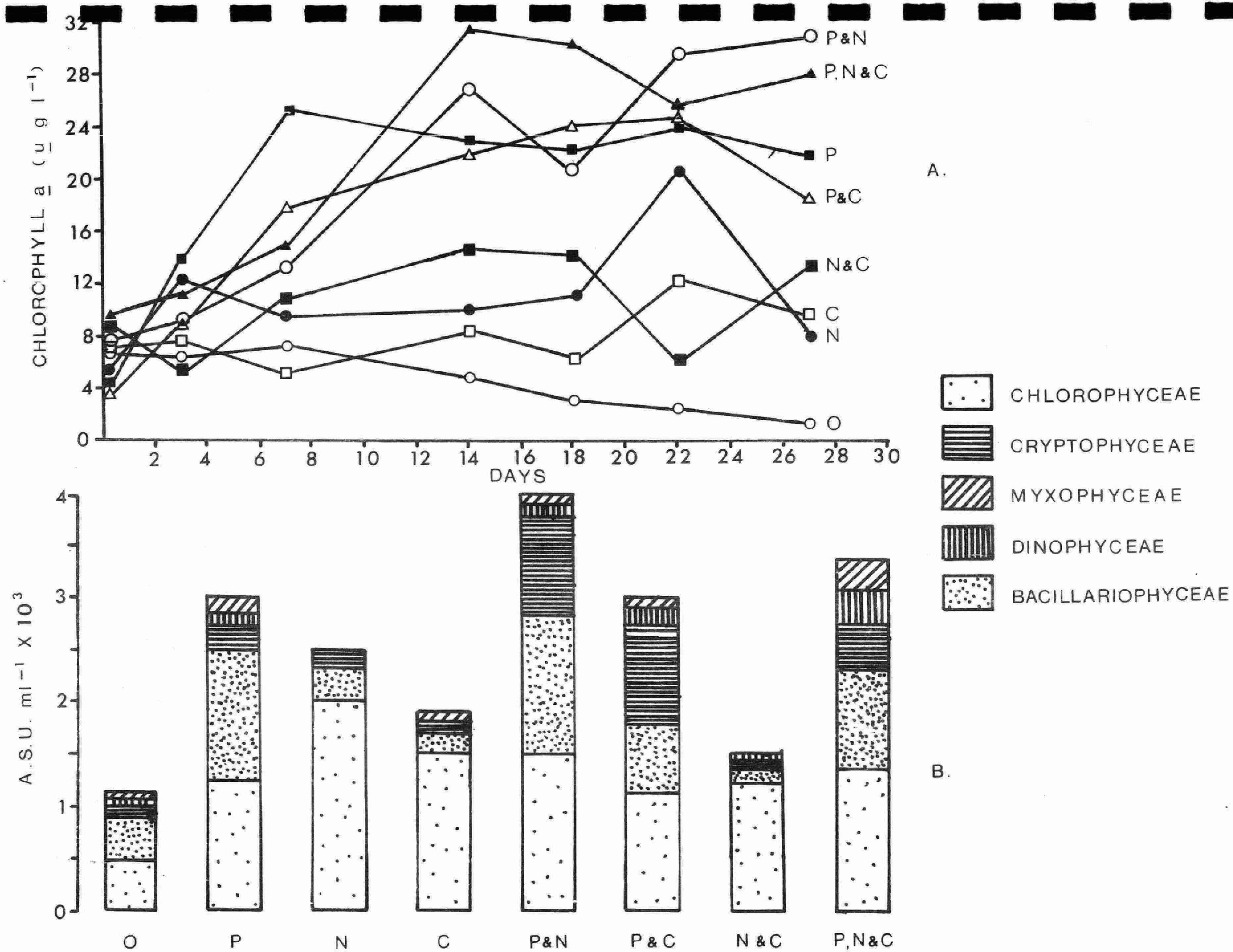

Figure 5.2: Chlorophyll a responses to additions of phosphorus, nitrogen and carbon, alone and in combination, to tubes set on June 24, 1969 at Station M-1 in Gravenhurst Bay. The control or reference tube is presented as the smaller open circles. Histograms (b) indicate standing stocks of phytoplankton (a.s.u. ml^{-1}) and relative percentages of the five main taxonomic classes on July 16.

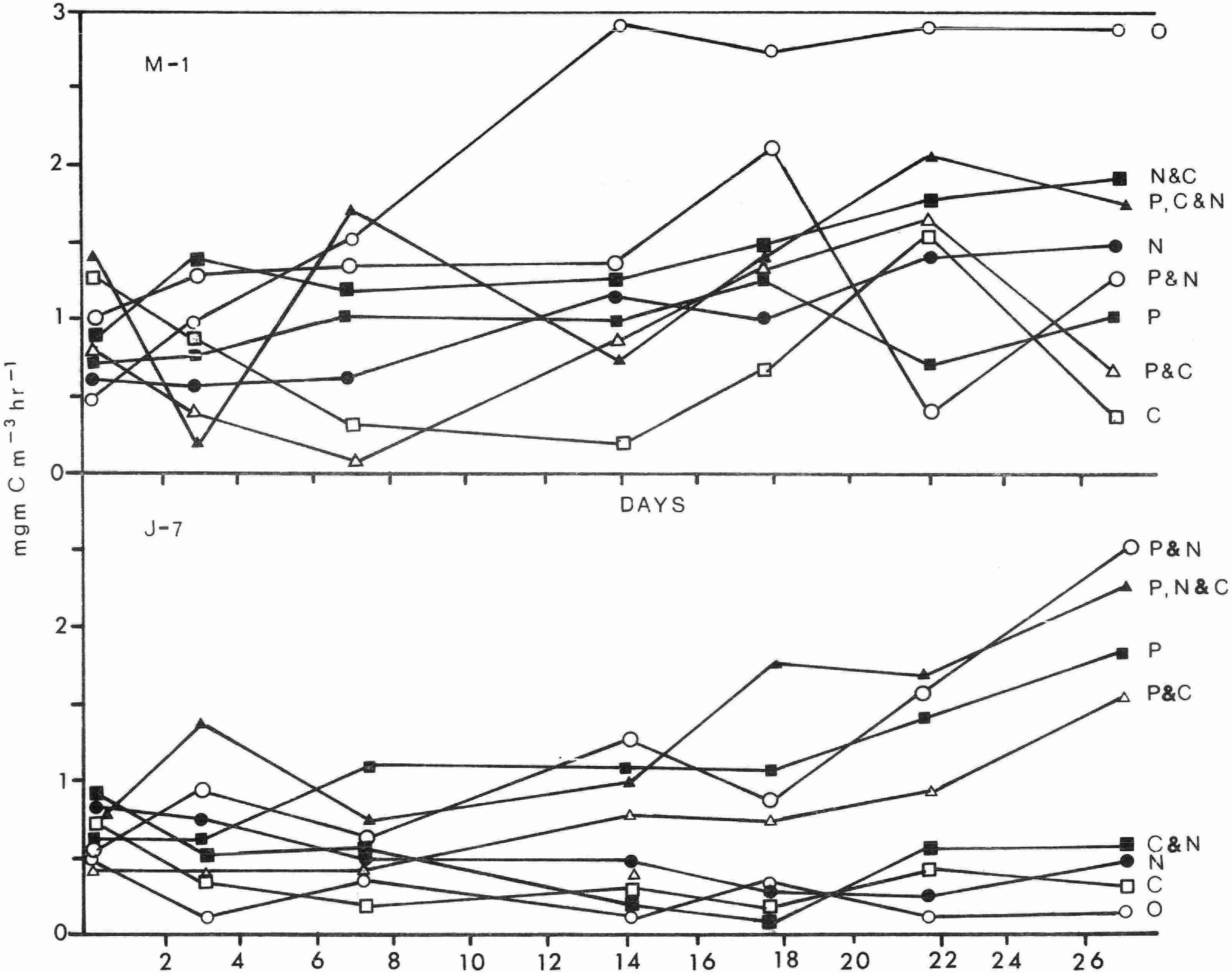

Figure 5.3: Production responses to additions of phosphorus, nitrogen and carbon, alone and in combination, to tubes set on June 24, 1969 at Station M-1 in Gravenhurst Bay (a) and at Station J-7 in Lake Joseph (b). Control or reference tubes are depicted as the smaller open circles.

Lakes Area and considered"....the fact that routine production measurements were always made before weekly nutrient additions, when minimum ^{14}C uptake would be expected, may be partially responsible." Similarly, our columns received nutrient additions immediately following all sample collections suggesting minimum carbon assimilation.

In summary, phosphorus was required to ensure increases in phytoplankton stocks and chlorophyll a concentrations. Nitrogen and carbon undoubtedly contributed to increase further algal densities when adequate phosphorus was available.

Experiment Number 2

Figures 5.4 presents the responses of chlorophyll a and standing stocks of phytoplankton to additions of treated and untreated secondary sewage effluents. As illustrated, lower responses were measured for those columns receiving the sewage wastes treated for phosphorus removal than bags treated with typical secondary sewage. Additionally, clearly defined shifts in phytoplankton dominancy did not materialize. The authors suggest that the relative short-term nature of the experiments did not allow adequate time for species changes to develop. Although we have presented data describing only the August responses for Gravenhurst Bay and Lake Joseph, similar overall trends were detected during the June study. However, it should be mentioned that changes from one column to the next were not as well-defined as those measured during August. Additionally, mid-way through the June set of experiments the control bag in Gravenhurst Bay and the column receiving secondary sewage effluents in Lake Joseph were lost owing to high wind and wave activities or vandalism.

Experiment Number 3

Relative to the control enclosure, elevated concentrations of total phosphorus, free ammonia, iron and silica were apparent in the column injected with nutrient-rich hypolimnetic water (Figure 5.5). Total Kjeldahl nitrogen and inorganic carbon levels were similar in both enclosures (Figure 5.6). Chlorophyll a and standing stocks of phytoplankton were

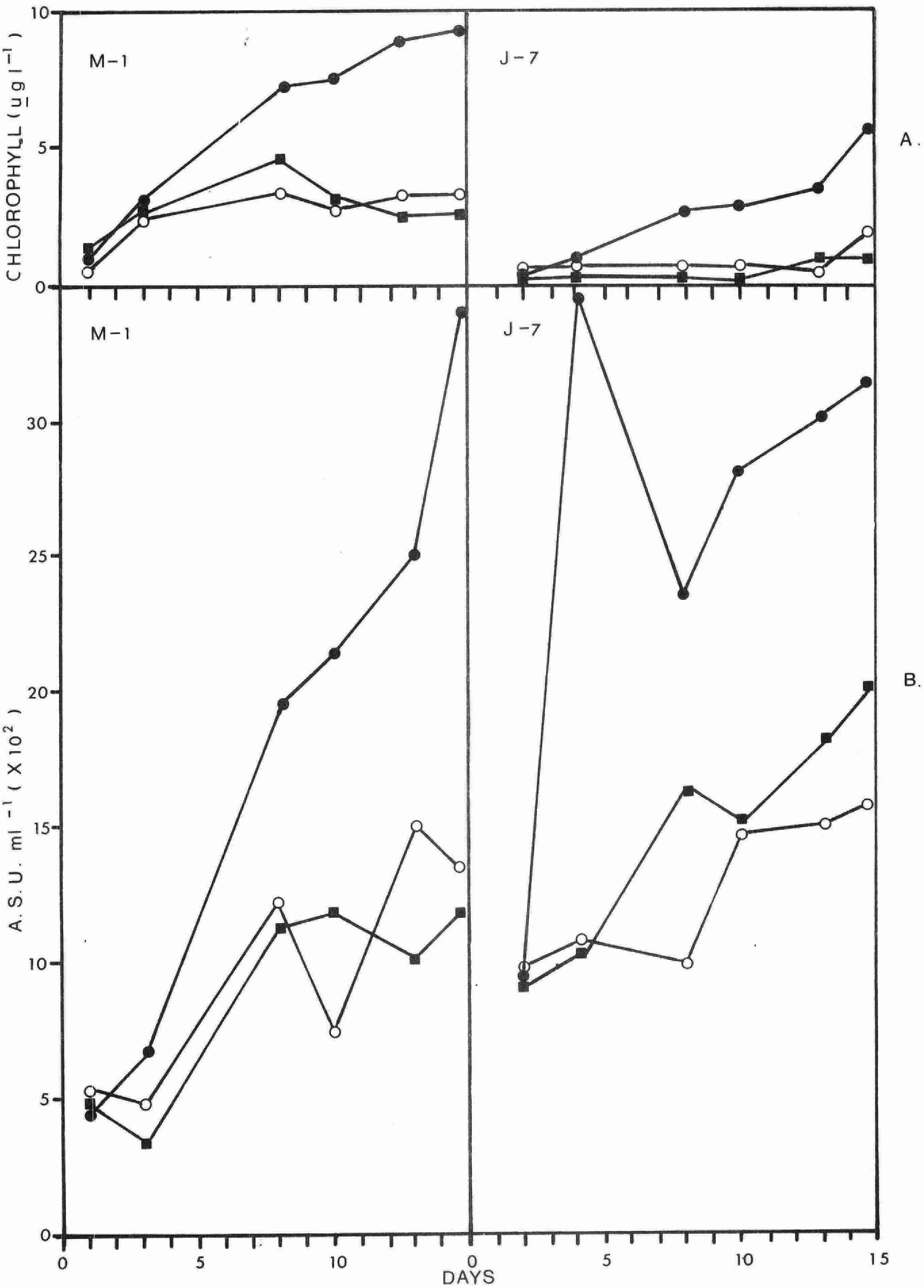

Figure 5.4: Responses of chlorophyll a (a) and phytoplankton (b) to additions of secondary sewage (closed circles) and secondary sewage treated with $Ca(OH)_2$ to remove phosphorus (closed circles). Injections were made to in situ tubes set in Gravenhurst Bay (M-1) and Lake Joseph (J-7). Closed circles represent conditions in control tube. Data depict collections on six occasions between August 18 and September 1, inclusive.

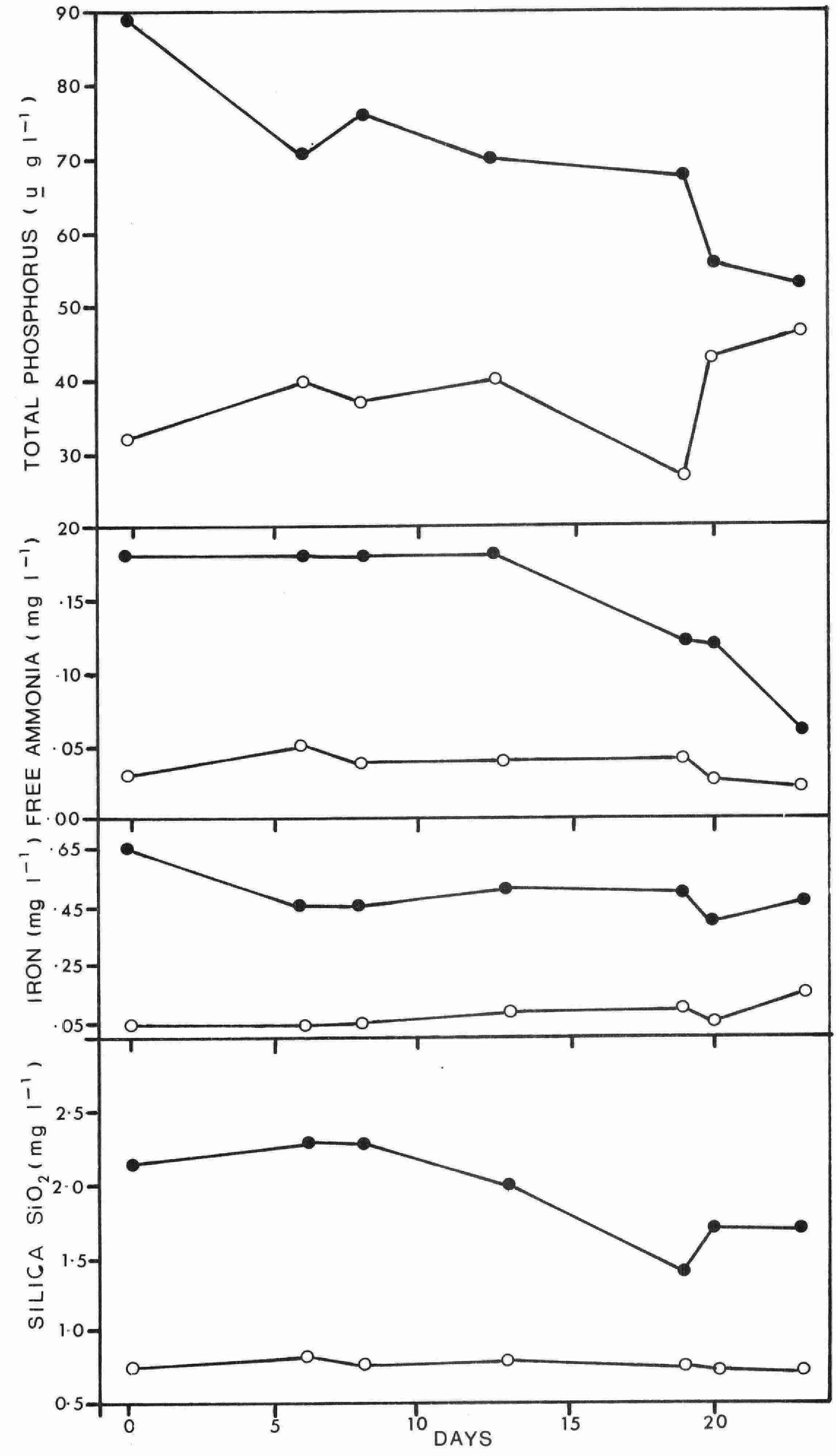

Figure 5.5: Concentrations of total phosphorus, free ammonia, iron and silica in an epilimnetic water column set in Gravenhurst Bay (M-1) and treated with 30% hypolimnetic water (closed circles). Open circles depict <u>in situ</u> epilmnetic conditions.

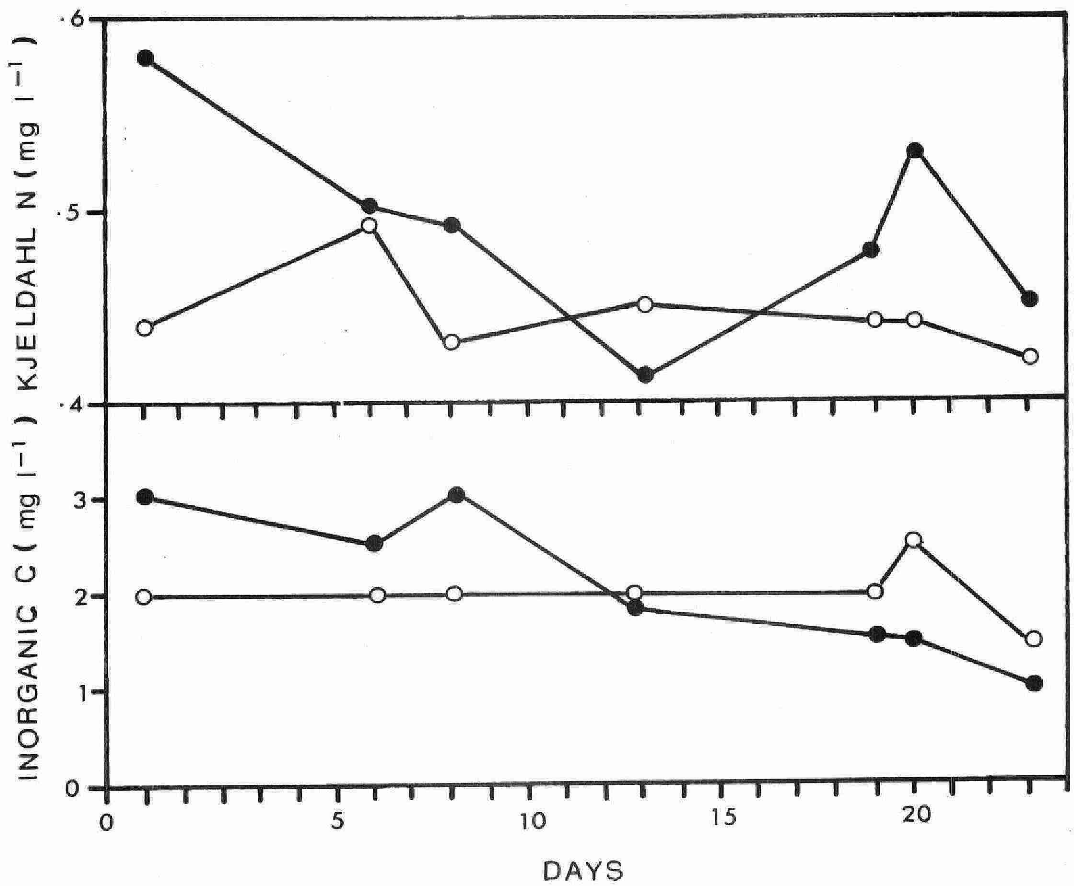

Figure 5.6: Concentrations of total Kjeldahl nitrogen and inorganic carbon in an epilimnetic column set in Gravenhurst Bay (M-1) and treated with 30% hypolimnetic water (closed circles). Open circles depict _in situ_ epilimnetic conditions.

initially depressed in the treated column; however, levels increased steadily over the experimental period and were highest on the last sampling day (Figure 5.7). In comparison to the control tube, algal densities in the hypolimnetic - enriched enclosure were decidely higher, considering the entire study period of 23 days. Chlorophyll a and a.s.u. depressions on day one of the experiment probably relate to dilution of euphotic zone water with the hypolimnetic addition. Highest rates of carbon assimilation occurred on the initial day (i.e. September 17) in the tube receiving hypolimnetic enrichment, thereafter, similar rates of carbon uptake for both tubes were recorded. This observation substantiates the claim of Schindler et al. (1971) that highest rates of ^{14}C uptake would be expected immediately following nutrient additions to a system.

The above results suggest that mixing of nutrients from the hypolimnion into overlying waters following the auturm turn-over may act to maintain and augment algal densities - at least in Gravenhurst Bay. Owing to the relatively short-term nature of the study, the entire matter of nutrient regeneration and water quality implications requires further comment to place our findings on a more realistic basis.

The vertical distribution of phosphorus during thermal stratification is quite different in nutrient-poor and productive lakes. In the former type of lake, relatively little variation with depth exists in either the reactive or total phosphorus fraction. Lakes having clinograde oxygen curves usually show significant increases in both fractions in the hypolimnion. During the late summer, such increases were clearly evident at 2m above bottom in Gravenhurst Bay and to a lesser extent in Dudley and Skeleton Bays. It is generally recognized that increases in the total phosphorus fraction are dependent mainly on sedimented seston. Currently, there is a good deal of conjecture concerning the release and fate of the soluble reactive phosphorus fraction from the sediments. For instance Einsele (1938), Mortimer(1941 and 1942) and Hutchinson (1957) have reported the release of molybdate reactive phosphorus from sediments during late summer. With specific reference to the Muskoka Lakes, Brydges (1970) concluded from a series of laboratory tests that up to 25% of the total

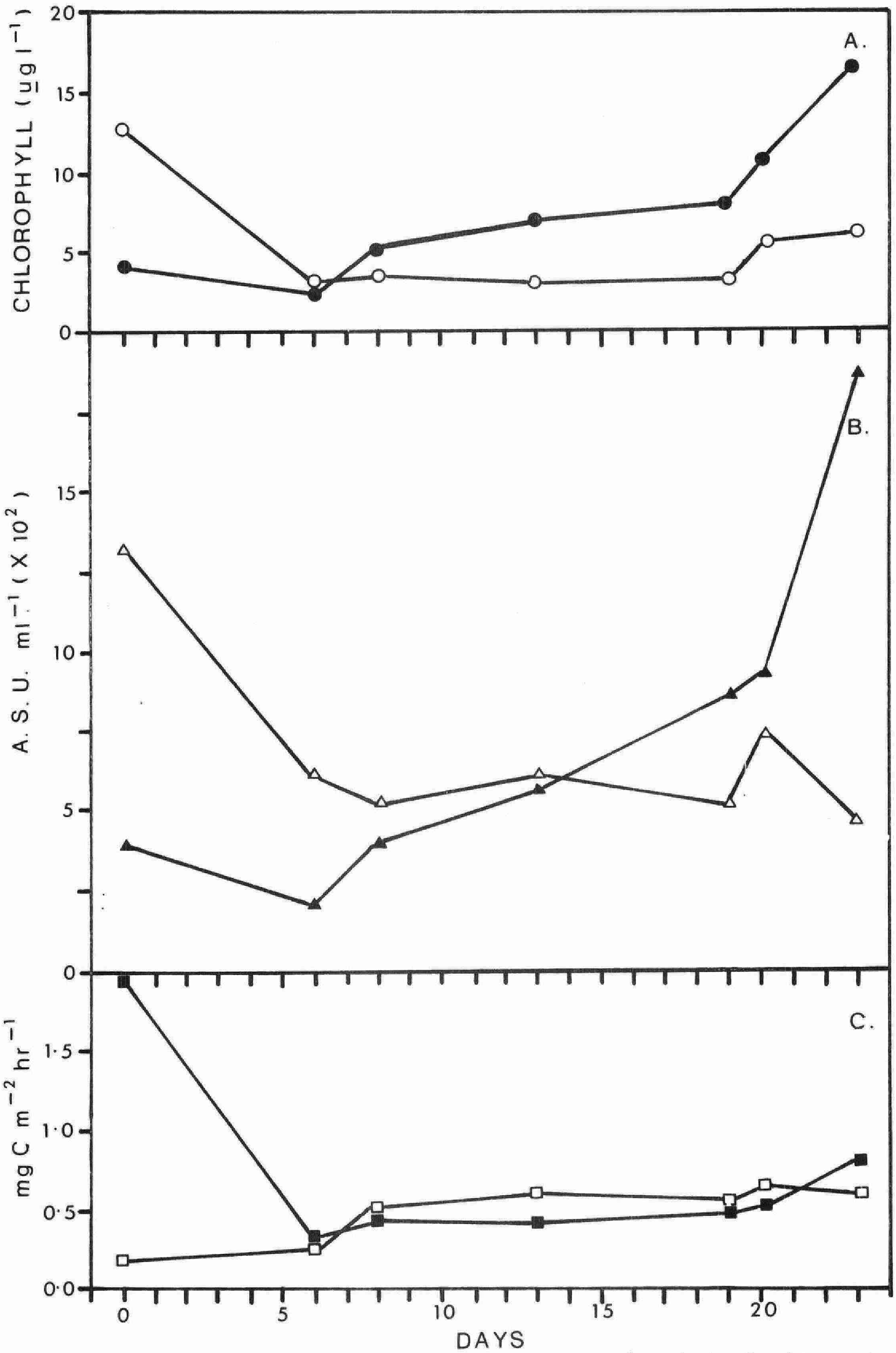

Figure 5.7: Changes in chlorophyll a (a, closed circles), phytoplankton stocks (b, closed triangles) and primary production (c, closed squares) following treatment of an epilimnetic water column with 30% hypolimnetic water. Open circles, triangles and squares indicate chlorophyll a concentrations, phytoplankton levels and production rates, respectively in tube containing epilimnetic water alone.

phosphorus in the sediments was released under anaerobic conditions while less than 1% of the total was fed back into solution under aerobic situations. The aforementioned authors suggested that such inputs could act to retard the recovery of an artificially-enriched lake once all man-made nutrient sources were eliminated. On the other hand, Schindler et al. (1971) did not find an increase in reactive phosphorus in the hypolimnion of Lake 227 - a relatively unproductive Shield lake near Kenora treated for 17 weeks with approximate loadings of phosphorus and nitrogen currently reaching the lower St. Lawrence Great Lakes and suggested that "...complete removal of external sources of phosphorus to a lake would probably allow it to return rapidly to its natural steady state condition." Following a series of sewage diversions from Lake Washington, Edmondson (1972) reported that the major reductions were in phytoplankton populations and phosphorus concentrations. Nitrate and carbon dioxide levels were not appreciably altered. Significantly, the author reported, "....it took only two years for the hypolimnetic release of phosphorus to return to the level of 1933 as judged by net accumulation during the summer."

The most glaring limitation of the three experiments outlined above is that each approach was designed from the point of view of adding nutrients to systems. Very few efforts have gone into "the taking away" of an element critical to plant growth. With respect to our approach Edmondson (1972) states that experiments of the aforementioned type ".....are capable of showing how a system will react to an increase in a nutrient, but they do not show how the system will react to a decrease, and that is what we need to know for purposes of control." Although the results of Experiment Number 3 suggest that the hypolimnetic-enriched waters may act to maintain and in fact, augment algal densities, one has no choice but to argue that removal of all artificial sources of phosphorus (as indicated by results of Experiments Numbers 1 and 2) is the logical initial step if water quality is to be improved in Gravenhurst Bay and maintained elsewhere in the study area.

CHAPTER 6

NUTRIENT BUDGET

CHAPTER 6 - NUTRIENT BUDGET

INTRODUCTION

Nutrient budgets were developed for Lakes Joseph, Rosseau and Muskoka and the four selected smaller sub-systems (Dudley, Skeleton and Gravenhurst Bays and Little Lake Joseph) for total phosphorus and total nitrogen using methods described previously (Owen and Johnson 1966, Neil, Johnson and Owen 1967 and Johnson and Owen 1971). Also, soluble reactive silica and total carbon, both of which could be of some significance in influencing primary production and composition of standing stocks of algae, were examined but mass-balances of these two nutrients were not attempted. Only reactive silica was measured; therefore the most that could be done was a calculation of loading rates for this available form to the main lakes and selected bays. Total carbon was budgeted with difficulty because of the lack of data on CO_2 exchange at the air-water interface. However, loading rates, which excluded possible air-water fluxes were calculated.

Nutrient inputs are categorized according to the following sources, 1) land drainage, 2) cottages, 3) resorts, 4) municipal wastes, 5) rainfall and 6) carry-over from upstream to downstream lakes. Inputs from these sources were not precisely determined, but estimates for all major inputs were calculated which are sufficiently reliable to permit an understanding of existing water quality and implications for future water management. Re-cycled nutrients, that is, from profundal sediments and littoral plants and sediments were not measured because extrinsic inputs were of primary concern to water management concepts.

METHODS

Land drainage

Rating curves (nutrient yield as a function of water yield) were calculated following established procedures (Johnson and Owen 1971) for the Rosseau and Dee Rivers flowing into Lake Rosseau, the Hoc Roc, North and South Muskoka Rivers which flow into Lake Muskoka and the Moon and Muskoka Rivers below Bala. Results were extrapolated from the Dee and Rosseau to miscellaneous land areas tributary to Lakes Joseph and Rosseau. Estimates of nutrient inputs from land drainage of miscellaneous areas tributary to Lake Muskoka were pro-rated from Hoc Roc River nutrient yields.

Municipal inputs

Annual capita inputs of phosphorus and nitrogen were taken from previous studies (Johnson and Owen 1971) with consideration of the degree of industrialization and type of waste treatment provided by Muskoka municipalities. Silica (soluble reactive) inputs per capita were obtained from three estimates of the daily yield from the Bala, Gravenhurst and Ontario Hospital waste treatment plants. Per capita carbon inputs were derived from C:N ratios in final effluents (nine samples) from Bracebridge, Gravenhurst, Bala and the Ontario Hospital. Nutrient inputs were 1.5 kg P, 4 kg N, 1.3 kg SiO_2 and 16 kg C per capita per year.

Cottage inputs

Obviously a large number of factors determine the capacity of the soil for retention of nutrients. For example, the length and intensity of occupancy determine to what degree this capacity has already been utilized or exceeded.

Available evidence indicates that no significant proportion of phosphorus is retained in conventional septic tank-tile field waste disposal systems (Hall 1970, Shannon and Brezonik 1972). Additional evidence is available from experiments on a tile-field soil to which phosphorus was added in core tubes in the laboratory. This work which is reported herein as a footnote[1] is being continued.

[1]The soil, a medium sand from a pit near Gravenhurst used in local tile-field construction, was placed in eight 4.4cm diameter tubes approximately 40cm long. Nutrient solution (50 mg litre $^{-1}$P as NaH_2PO_4 in a $NaHCO_3$ solution of 20 mg litre $^{-1}$ to simulate the soft lake water of the area) was added daily and the effluent which drained directly into sample bottles and removed for analysis each week. The amount of water added per unit area was the same as that added by four persons serviced by a 1,000 square foot (92.9 m^2) tile field. The areal rate of addition of phosphorus, and also the concentration, were ten times the corresponding design rate of application of phosphorus. Equivalent man-days (in terms of phosphorus) were calculated. Also, two cores received sodium suphite solution and two received starch and proteose-peptone solution in attempts to stimulate anaerobic conditions. The percentage of phosphorus removed each week and the accumulation of phosphorus in the cores were measured. When removal decreased to below 50%, often falling to below 20%, deionized water was added to some cores for several weeks to determine the amount of phosphorus "unloaded", as if by natural rainfall. In general, cores retained less than 50% of added phosphorus after 1-2 man-years equivalent loading. Removal rates of phosphorus decreased to below 50% after approximately 100mg of phosphorus (about 0.13mg gram^{-1} of soil or 0.013%) had been added, equivalent to about 400 man-days. By the time that 800 man-days equivalent had been added, the efficiency of phosphorus removal was usually 10 to 20% except where bacteria had been stimulated (with starch and proteose-peptone solution) in which case removal was 40 to 50%. When phosphorus additions were halted and deionized water percolated through the cores, a variable amount of phosphorus was "unloaded" amounting to between 20 and 55% depending on the ancilliary treatments. Cores enriched with starch and proteose-peptone solution lost only 20 to 25%, while the sulphite treated cores (which had lost proportionately more of their iron) lost 45 to 55%. Although this work is being continued, and other soils are under examination, it is apparent that the sandy Precambrian soils may be of minimal value as tile bed soils because their capacity to retain phosphorus is limited and a considerable proportion may be held only temporarily, that is until percolating rain-water washes phosphorus through to base flows.

Considering the aforementioned, it seems expedient at present to assume that no more nutrients are removed in the cottage disposal systems than in the average secondary waste treatment plant (i.e. 20-40%)

Therefore, the per capita contributions forming municipal inputs were used to obtain cottage contributions. Cottages throughout the system were counted and average man-years occupancy per cottage unit were available from mail survey data reported previously (Michalski and Robinson 1971). These were 1.0 man-year per cottage unit on Lake Joseph and 0.75 man-year per unit on Lakes Rosseau and Muskoka.

Resort inputs

Most resorts use sewage-oxidation ponds for domestic waste treatment. Nutrient removal from these systems is apparently quite low. Per capita yields of nutrients from resorts were probably similar to those values used for municipal and cottage wastes. Yearly input estimates were computed by acquiring data on man-years occupancy for each lodge and resort and applying per-capita yields. If in error, the resort inputs probably were underestimated, because of the expected heavier than average use of detergents and other washing compounds.

Rainfall contributions

Annual inputs of phosphorus and nitrogen were taken as 17 kg km^{-2} (100 lb P mile $^{-2}$) and 873 kg km^{-2} (5,000 lb N mile $^{-2}$), respectively (after Johnson and Owen 1971).

Carbon concentrations of 0.2 mg C litre $^{-1}$ were computed from information supplied by Sverdrup et al. (1942). A loading estimate based on annual precipitation of 90.0cm was calculated as 201 kg km^{-2} (1,140 lb C $mile^{-2}$) for this study.

Silica inputs were estimated from data provided by Schindler and Nighswander (1970) for Clear Lake, an 0.88 km^2 lake east of the Muskoka study area which received an annual average precipitation of 90.0cm. The estimate used for this study was 164 kg silica km^{-2} $year^{-1}$ (i.e. 935 lbs silica mile $^{-2}$ $year^{-1}$).

Carryover from upstream lakes

Nutrient carryovers from Lake Joseph into Lake Rosseau and from the latter into Lake Muskoka were estimated by comparing inputs and outputs for Lake Muskoka and approximating the amount lost from the lake. The

relative losses for each nutrient were then applied to total inputs to Lakes Rosseau and Muskoka to obtain carryover. Approximately 20% of the total phosphorus and 50% of the nitrogen carbon and reactive silica loadings were carried over from Lakes Joseph to Rosseau and from the latter to Lake Muskoka.

HYDROLOGY

Watershed areas and mean flows of the main tributaries to the three lakes are shown in Table 6.1. The total watershed area at Bala including the area of the three lakes is 4,610 km^2, and the average outflow is 4,804 m^3 min^{-1}. The watershed area of Lake Muskoka, and hence the inflow, are much greater than watershed areas and inflows of the other two lakes. The average inflow into Lake Muskoka via the Muskoka River was slightly over 3,400 m^3 min^{-1}, which was almost 75% of the outflow from the system at Bala. An additional 12% of this outflow, about 588 m^3 min^{-1}, entered Lake Muskoka at Port Carling. In contrast, Lake Joseph received an estimated average inflow from 127 km^2 of about 114 m^3 min^{-1}, while Lake Rosseau received an average flow of 588 m^3 min^{-1} from 716 km^2. Therefore, turnover times (volume divided by annual inflow) are 0.9 year in Lake Muskoka, 4.8 years in Lake Rosseau and 20.9 years in Lake Joseph. The calculations were based on the approximate equality of evaporation from and rainfall on the lakes. Note that the sum of inputs, 4,410 m^3 min^{-1} was about 10% less than the measured outflow, 4,804 m^3 min^{-1}, which is likely the result of experimental errors and perhaps some excess of rainfall over evaporation (rainfall on the lakes represented about 450 m^3 min^{-1}).

The watershed areas and approximations of inflow (pro-rated from watersheds where flows were available) of the four selected bays are given in Table 6.1. Turnover times vary between 0.2 year in Skeleton Bay with its relatively large watershed to 2.3 years in Little Joseph Bay. Dudley and Gravenhurst Bays had theoretical turnover times of 1.4 and 1.8 years, respectively. The turnover time of Dudley Bay is over-estimated because it does not include the probable

Table 6.1: Areas and estimated mean flow for each sub-watershed of the Muskoka Lakes system.

Tributary to	Watershed	Area (km^2)	Mean Flow ($m^3\ min^{-1}$)
Main Lakes			
Joseph	Total	126.7	114
Rosseau	Dee River	158.0	119
	Rosseau River	142.5	151
	Skeleton River	90.7	66
	Shadow River	59.6	61
	Miscellaneous	89.1	77
	Joseph @ Joseph River	176.5	-
	Total	716.4	
Muskoka	North Muskoka River	1,570.8	1,741
	South Muskoka River	1,679.4	1,692
	Hoc Roc River	61.6	46
	Miscellaneous	395.5	343
	Rosseau @ Port Carling	774.8	-
	Total	4,482.1	4,410
Lake System	Total @ Bala	4,610.1	4,804
Bays			
Little Joseph	Total	36.9	33
Skeleton	Total	206.6	150
Dudley	Total	43.3	32
Gravenhurst	Total	37.3	29

NOTE $m^3\ min^{-1} \times 0.59$ - cfs

movements of water in and out of the bay at the northern and southern ends, respectively. Gravenhurst Bay, on the other hand, is the most effectively isolated of the four bays studied and the calculated turnover time should be realistic. Similarly, Little Joseph Bay is almost isolated. However, Skeleton Bay water is likely exchanged with Lake Rosseau water to a significant extent.

NUTRIENT SOURCES

River contributions

Phosphorus concentrations were relatively low in the monitored rivers, ranging from 10 to about 35 $\mu g\ l^{-1}$ (Table 6.2). Yields of phosphorus via inflowing rivers varied from 7.8 to 24.4 kg km^{-2} $year^{-1}$ (Table 6.3). Most of these are close to yields estimated for the Trent, Moira, Salmon and Napanee Rivers, 7.0 to 13.9 kg km^{-2} $year^{-1}$. Very close to 10 kg km^{-2} of the North Muskoka yield may be accounted for by the municipality of Huntsville (population 6,283), making the range, excluding Huntsville, 7.8 to 14.4 kg km^{-2} $year^{-1}$. The annual yield from the system (at Bala) was 4.8 kg km^{-2}.

Nitrogen concentrations ranged from 406 to 625 $\mu g\ l^{-1}$ and annual yields via the inflowing rivers varied between 172 and 731 kg km^{-2} (Table 6.3).Nitrogen yields from the four Quinte watersheds varied between 184 and 301 kg km^{-2}. The North Muskoka River, which included Huntsville's contribution showed the highest nitrogen yield. The annual nitrogen yield from the total system was 226 kg km^{-2}.

Carbon concentrations were 7.1 to 15.3 mg l^{-1} and annual yields were 3,893 to 13,500 kg km^{-2}. Silica concentrations, which include only molybdate reactive silicates, were 2.7 to 4.1 mg l^{-1} and yields from contributing watersheds varied between 835 and 7,809 kg km^{-2}. The output from the system at Bala represented yields of 4,059 kg carbon and 1,670 kg reactive silicates per km^2 in 1969 (see Tables 5.2 and 6.3).

Table 6.2: Mean flows in 1969 and mean concentrations of total phosphorus, nitrogen, carbon and molybdate reactive silica in five main tributaries to the study lakes. Outflow is via the lower Muskoka and Moon Rivers. Each river was sampled 30 times in 1969.

River	Mean flow (m^3 min^{-1})	Phosphorus (μg l^{-1} ± 2 S.E.)	Nitrogen (μg l^{-1} ± 2 S.E.)	Carbon (mg l^{-1} ± 2 S.E.)	Silica (mg l^{-1} ± 2 S.E.)
Dee	119	22.9 ± 1.9	534 ± 1.66	10.6 ± 0.4	3.35 ± 0.34
Rosseau	151	33.7 ± 6.0	625 ± 96	14.5 ± 0.4	3.30 ± 0.32
Hoc Roc	46	34.9 ± 5.2	632 ± 78	15.3 ± 1.24	2.75 ± 0.4
North Muskoka	1,741	14.9 ± 4.6	406 ± 48	8.4 ± 0.34	4.14 ± 0.30
South Muskoka	1,692	12.2 ± 2.2	406 ± 62	7.1 ± 0.54	2.98 ± 0.15
Lower Muskoka	3,874	10.0 ± 2.8	456 ± 98	7.2 ± 0.44	2.75 ± 0.21
Moon River	930	10.1 ± 1.7	415 ± 66	7.7 ± 0.90	2.70 ± 0.22

Table 6.3: Yields of total phosphorus, nitrogen and carbon and reactive silica per km^2 of main tributary watersheds and of the total system in 1969.

River	Annual yields (kg km^{-2})			
	Phosphorus	Nitrogen	Carbon	Silica
Dee	7.8	172	3,893	1,320
Rosseau	10.3	262	6,371	1,710
Hoc Roc	9.1	211	4,737	835
North Muskoka	24.4	731	13,560	7,809
South Muskoka	14.3	582	11,702	5,008
Lower Muskoka) Moon River)	4.8	226	4,059	1,670

The seasonal variation in nutrient inputs is pronounced (Figures 6.1 and 6.2 show the monthly variation in yields of phosphorus and nitrogen). Decreased river inputs of nutrients in July, August and September must be considered when relating nutrient loadings to the development of algal populations.

Municipal, cottage and resort inputs

Annual inputs for phosphorus, nitrogen, carbon and reactive silica from the major municipalities are given in Table 6.4. Similar loading data for cottage and resort inputs are provided in Table 6.5.

Other inputs

Contributions in rainfall on the lake surface were estimated in very approximate fashion, but, in absolute amounts, these are apparently significant contributions only in the case of phosphorus and nitrogen in lakes such as Joseph which have limited inputs via land drainage. Nutrient contributions in rainfall are shown in Tables 6.6 to 6.9.

Carryover of nutrients from Lake Joseph to Lake Rosseau and from the latter to Lake Muskoka were roughly estimated but must be included. These are important to Lake Rosseau, contributing 9 - 14% of nutrient loadings, but of much less significance to Lake Muskoka because of the large loadings via the Muskoka River and from the two main municipalities.

Comparison of inputs

Lake Joseph received almost one-half of its phosphorus loading from cottage and resort wastes, while runoff from a rather limited watershed and rainfall on the lake surface contributed about one-quarter each (Table 6.6). Nitrogen was supplied mainly in land drainage (Table 6.7) and rainfall probably contributed almost twice the nitrogen that was derived from cottage and resort wastes. Carbon and reactive silica were contributed primarily in land drainage (Tables 6.8 and 6.9, respectively).

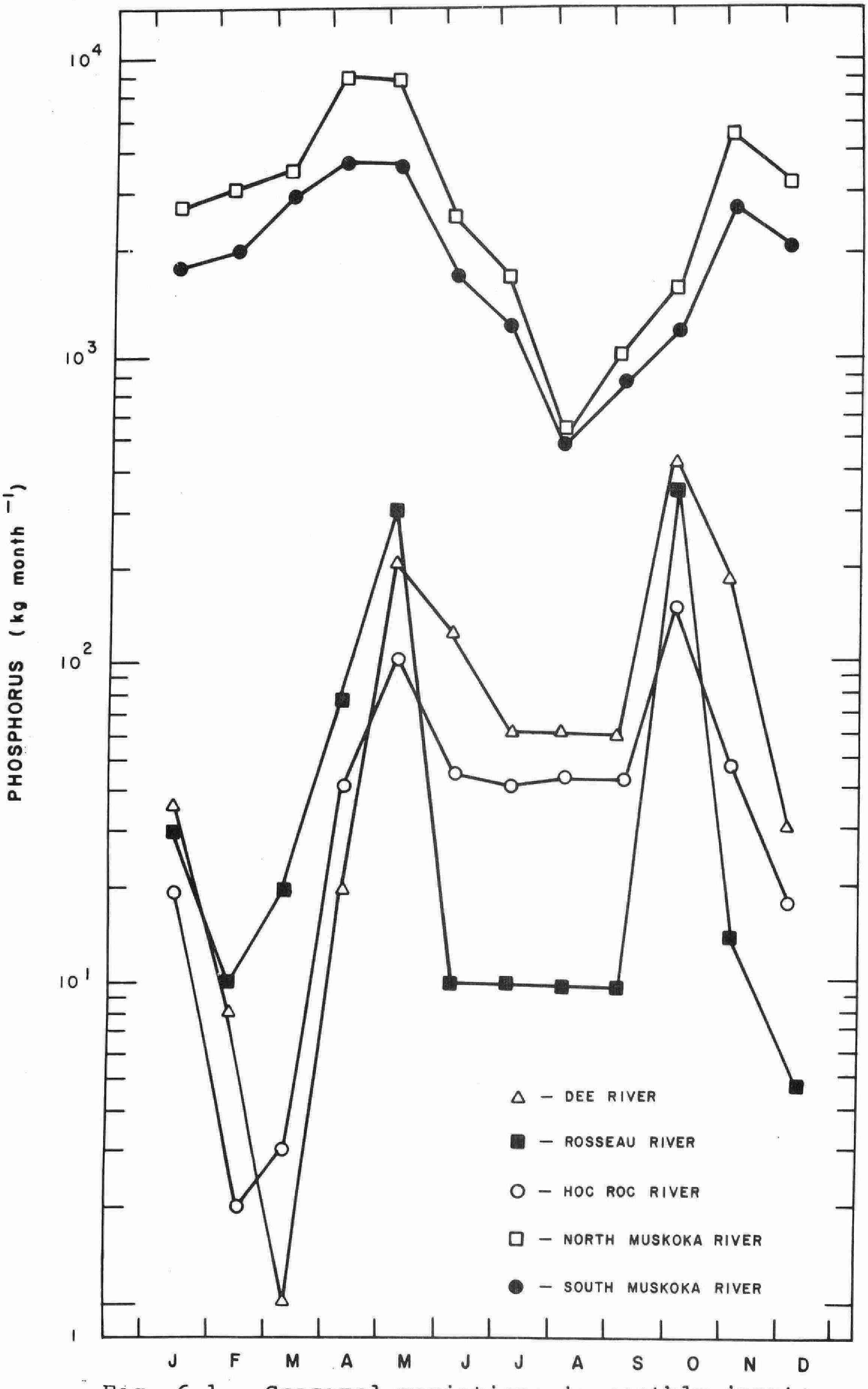

Fig. 6.1 Seasonal variations in monthly inputs of phosphorus

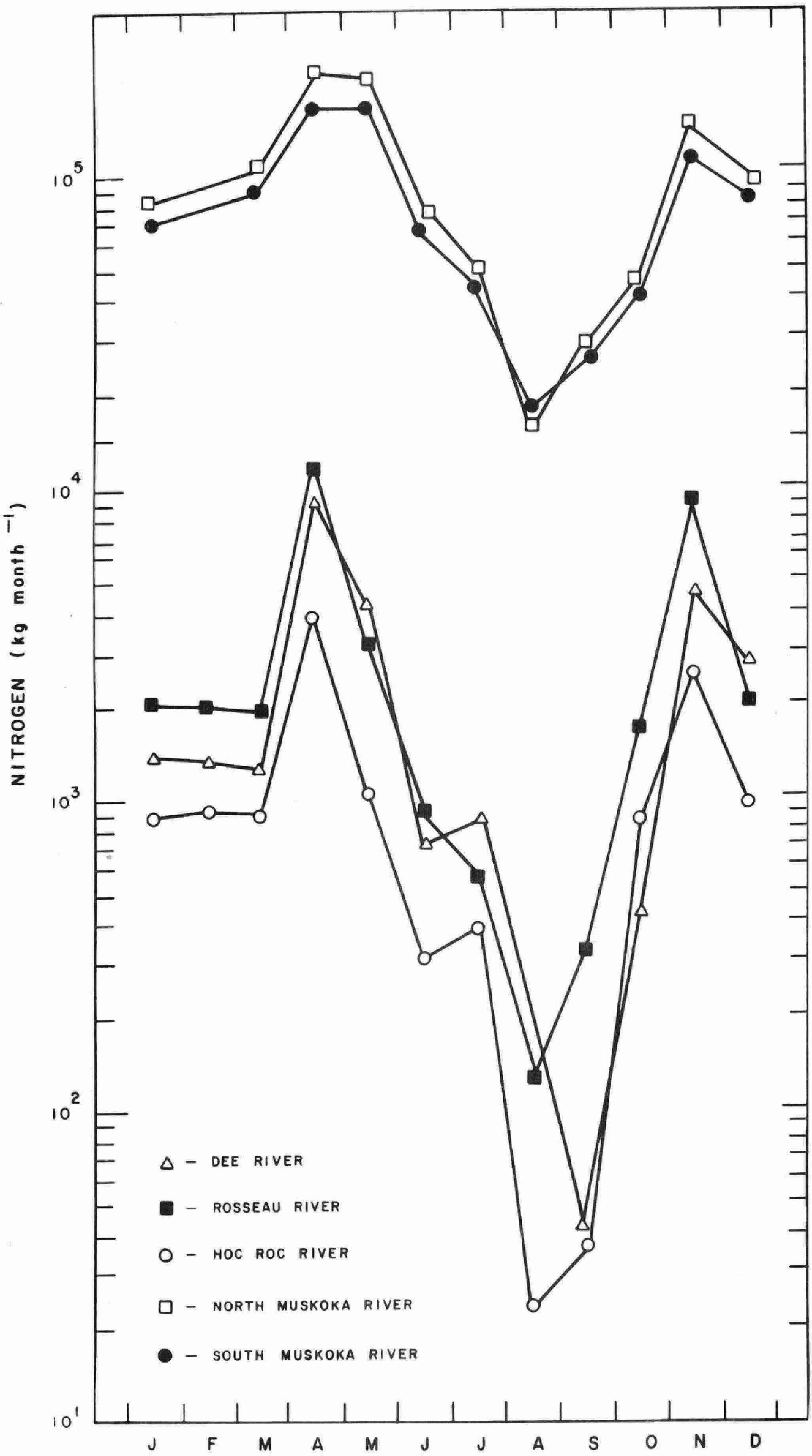

Fig. 6.2 Seasonal variation in monthly inputs of nitrogen

Table 6.4: Annual inputs of phosphorus, nitrogen, carbon and silica from municipal waste sources to Lakes Rosseau and Muskoka.

Source	Phosphorus kg $year^{-1}$	Nitrogen kg $year^{-1}$	Carbon kg $year^{-1}$	Silica kg $year^{-1}$
Rosseau	360	960	3,840	314
Gravenhurst and Ontario Hospital	8,933	23,820	95,280	7,801
Bracebridge	9,674	25,800	103,200	8,450
Port Carling	840	2,240	8,960	734
Bala	750	2,000	8,000	655
Total	20,557	54,820	219,280	17,954

Table 6.5: Annual inputs of phosphorus, nitrogen, carbon and silica from cottage and resorts to Lakes Joseph, Rosseau and Muskoka and selected bays.

Source	Cottages		Resorts		Loading (kg $year^{-1}$)			
	Number	Man-years	Number	Man-years	Phosphorus	Nitrogen	Carbon	Silica
Main Lakes								
Joseph	1,109	1,109	2	100	1,814	4,836	19,344	1,592
Rosseau	1,543	1,157	3	184	2,012	5,364	21,456	1,743
Muskoka	4,799	3,600	4	223	5,734	15,292	61,168	6,131
Bays								
Little Lake Joseph	81	81	-	-	121	324	1,296	106
Skeleton	45	34	-	-	51	146	544	45
Dudley	208	156	-	-	234	624	2,496	204
Gravenhurst	299	225	-	-	338	900	3,600	295
Total	8,084	6,362		507	10,304	27,486	109,904	10,116

Table 6.6: Absolute inputs of phosphorus from land, municipal, recreational and rainfall sources to Lakes Joseph, Rosseau and Muskoka and to the four selected bays in the watershed, 1969.

Source	LAKES						BAYS							
	Joseph		Rosseau		Muskoka		Gravenhurst		Dudley		Skeleton		Little Joseph	
	kg	%	kg	%	kg	%	Kg	%	kg	%	kg	%	kg	%
Land drainage	1,133	29.9	4,807	53.8	65,698	68.7	340	3.5	395	57.3	1,603	95.3	329	67.1
Cottage input	1,664	43.9	1,736	19.4	5,400	5.6	338	3.5	234	34.0	51	3.0	121	24.7
Resort input	150	3.9	276	3.1	335	0.4	-	-	-	-	-	-	-	-
Municipal input	-	-	360	4.0	20,197	21.2	8,933	92.3	-	-	-	-	-	-
Rainfall	847	22.3	993	11.2	2,176	2.3	69	0.7	60	8.7	28	1.7	40	8.2
Main lake above	-	-	759	8.5	1,786	1.8	-	-	-	-	-	-	-	-
Total	3,794		8,931		95,592		9,680		689		1,682		490	
Loading rate ($g\ m^{-2}\ yr^{-1}$)		0.076		0.153		0.747		2,370		0.195		1.026		0.210

NOTE: kg x 2.2 = lb.

Table 6.7: Absolute inputs of nitrogen from land, municipal, recreational and rainfall sources to Lakes Joseph, Rosseau and Muskoka and to the four selected bays in the watershed, 1969.

Source	LAKES						BAYS							
	Joseph		Rosseau		Muskoka		Gravenhurst		Dudley		Skeleton		Little Joseph	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Land drainage	27,483	67.0	114,132	75.4	2,218,269	92.9	7,870	23.7	9,136	88.1	35,535	98.8	8,004	91.7
Cottage input	4,436	10.8	4,629	3.1	14,400	0.7	900	2.7	624	6.0	146	0.4	324	3.7
Resort input	400	1.0	736	0.5	902	0.0	-	-	-	-	-	-	-	-
Municipal input	-	-	960	0.6	53,860	2.3	23,820	71.5	-	-	-	-	-	-
Rainfall	8,665	21.2	10,162	6.8	22,272	0.9	710	2.1	616	5.9	285	0.8	405	4.6
Main lake above	-	-	20,492	13.6	75,555	3.2	-	-	-	-	-	-	-	-
Total	40,984		151,111		2,385,258		33,300		10,376		35,966		8,733	
Loading rate ($g\ m^{-2}\ yr^{-1}$)		0.823		2,587		18,635		8.162		2.931		21.930		3.748

NOTE: kg x 2.2 = lb

Table 6.8: Absolute inputs of total carbon from land, municipal, recreational and rainfall sources to Lakes Joseph, Rosseau and Muskoka and to the four selected bays in the watershed, 1969.

Source	LAKES						BAYS							
	Joseph		Rosseau		Muskoka		Gravenhurst		Dudley		Skeleton		Little Joseph	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Land drainage	641,142	98.9	2,477,050	87.3	43,266,312	96.3	176,690	64.0	205,112	98.4	1,060,271	99.9	189,371	99.1
Cottage input	1,744	0.3	18,512	0.7	57,600	0.1	3,600	1.3	2,496	1.3	544	0.06	1,296	0.7
Resort input	1,600	0.2	2,944	0.1	3,568	0.0	-	-	-	-	-	-	-	-
Municipal input	-	-	3,840	0.1	215,440	0.5	95,280	34.4	-	-	-	-	-	-
Rainfall	9,110	1.6	10,540	0.9	23,140	<0.1	738	0.3	640	0.3	297	0.03	421	0.2
Main lake above	-	-	323,911	11.4	1,415,085	3.1	-	-	-	-	-	-	-	-
Total	653,596		2,836,797		44,981,145		276,308		208,248		1,061,112		191,088	
Loading rate ($gm^{-2}\ yr^{-1}$)	13,124.4		48,575.8		351,415.2		67.6		58.7		646.9		81.9	

NOTE: kg x 2.2 = lb

Table 6.9: Absolute inputs of molybdate reactive silica from land, municipal, recreational and rainfall sources to Lakes Joseph, Rosseau and Muskoka and to the four selected bays in the watershed, 1969.

Source	LAKES						BAYS							
	Joseph		Rosseau		Muskoka		Gravenhurst		Dudley		Skeleton		Little Joseph	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Land drainage	189,500	95.1	781,576	87.5	29,464,991	98.4	31,145	78.0	36,155	97.8	272,712	99.9	55,350	99.1
Cottage input	1,453	0.7	1,515	0.2	4,716	0.1	295	0.7	204	0.6	45	<0.1	106	0.2
Resort input	131	<0.1	241	<0.1	292	-	-	-	-	-	-	-	-	-
Municipal input	-	-	314	<0.1	17,640	<0.1	7,801	19.5	-	-	-	-	-	-
Rainfall	8,167	4.1	9,578	1.1	20,992	<0.1	669	1.7	580	1.6	269	0.1	382	0.7
Mean lake above	-	-	99,620	11.1	446,442	1.5	-	-	-	-	-	-	-	-
Total	199,251		892,844		29,955,053		39,910		36,939		273,026		55,838	
Loading rate ($gm^{-2}yr^{-1}$)		4.001		15.288		234.023		9.781		10.434		166.479		23.964

NOTE: kg x 2.2 = lb

Because Lake Rosseau watershed is larger than that of Lake Joseph, it received about 60% of the phosphorus in land drainage and only about 20% from cottage and resort wastes. Land drainage contributed 89% of the nitrogen and 99% of the carbon and reactive silica to the loadings of the lake. Carryover from Lake Joseph was included in land drainage, although it is itemized in Tables 6.6 to 6.9.

About 20% of the phosphorus loading to Lake Muskoka was from municipal sources and 6% from cottage and resort wastes. However, this is a result of the large input in land drainage, particularly via the Muskoka River. In spite of the low percentage contributions by municipalities, cottages and resorts, together they contributed almost 26,000 kg to Lake Muskoka, which was several times the total loading from all sources to Lake Joseph. Approximately 96% of the nitrogen loading to Lake Muskoka was in land drainage, including carryover from Lake Rosseau. Practically all of the carbon and reactive silica originated in land drainage.

Gravenhurst Bay was heavily loaded with nutrients from municipal wastes. About 90% of phosphorus, 70% of nitrogen and, in fact, one third and one-fifth of carbon and reactive silica, respectively originated in municipal wastes. In comparison cottage inputs were low (Tables 6.6 to 6.9).

Dudley Bay received one-third of its phosphorus loading from cottage wastes, while the other nutrients were mainly from land drainage. In fact, nitrogen loadings from cottages and rainfall on the bay were probably similar. Skeleton Bay, with a relatively large inflow, received almost all nutrients from land drainage; only 3% of the phosphorus and less than 1% of nitrogen were attributable to cottage wastes. Little Joseph, with a smaller watershed, received about 25% of phosphorus from cottage wastes and the 8% in rainfall also may be significant. Only 4% of nitrogen was from cottage wastes in Little Joseph Bay.

Comparison of absolute inputs does not provide information on the effects of various inputs and sources in changing nutrient concentrations (Johnson and Owen 1971). A municipal waste treatment plant may have 100 times the concentration of phosphorus as that in an inflowing river

(for example, 3.5 mg l^{-1} in treatment plant effluent and 0.035 mg l^{-1} in a river). The effect of the plant effluent in all cases will be to increase the concentration of a nutrient in the receiving waters. On the other hand, the river may decrease the concentration in the receiving water, if the inflowing river has a concentration of nutrient lower than that in the water body. It is extremely important to discriminate between low-volume, high-concentration inputs and high-volume, low-concentration inputs. Johnson and Owen (1971) attempted to do this by calculating "net inputs" as the difference between the absolute input and the amount of nutrient displaced at the outlet in an equivalent flow. This analysis seems appropriate, but it should be reccgnized that net inputs must be recalculated following a reduction in size of any one or more inputs. For example, a river may be acting to decrease the nutrient concentration in a receiving lake while a high-concentration input is present, but this same river could increase nutrient concentrations in the lake if the high-concentration input was reduced or diverted.

It was possible to estimate and compare net inputs of phosphorus and nitrogen for the total three-lake system, but this was not possible on an individual lake and bay basis because of the lack of information on their outflows. However, concentrations in the outflow at Bala are available. These allow calculations of net input of the five rivers which were sampled, and the data may be used to pro-rate the net input of the remainder of the watershed tributary to the system. Cottage and resort net inputs are identical with their absolute inputs because in most instances water supply is from the lake, that is, they do not displace water from the system. The municipal net inputs are close enough to absolute inputs, that the latter may be used for the purpose of this analysis (Table 6.10).

Land drainage contributed almost one-half of the net input of phosphorus, but none of the net input of nitrogen. Collectively, the rivers displaced more nitrogen than they added, the result of the inflowing Muskoka River having a lower concentration of total nitrogen than that in the outflow. That is, the Muskoka River, at that point in time, was acting to decrease the nutrient concentration in Lake Muskoka. Cottage and resorts contributed about 15% of the net input of phosphorus and about 25% of the

Table 6.10: Comparison of net inputs of phosphorus and nitrogen in the total system above Bala. Net input of nitrogen in land drainage was negative; this was taken as zero when percentages were calculated.

Source	Phosphorus (kg)		Nitrogen (kg)	
	Net input	%	Net input	%
Land drainage	31,902	48.3	(-50,022)	-
Cottage input	8,800	13.3	23,465	23.9
Resort input	761	1.2	2,038	2.1
Municipal input	20,557	31.1	54,820	55.8
Rainfall	4,016	6.1	17,878	18.2
Total	66,036		98,183	

net input of nitrogen. Municipalities appeared to be more significant, as they added 31% of the phosphorus and 56% of the nitrogen to net inputs. It is interesting that rainfall contributes to net inputs in this system, accounting for 6% of the phosphorus and 18% of the nitrogen in net inputs.

Unfortunately, this method of placing waste sources into more realistic perspective, in terms of their effects on increasing nutrient concentrations in receiving waters, cannot be calculated for each lake and bay. However, the rationale, in being developed for the whole system, should be better understood and its potential application to sub-systems appreciated.

NUTRIENT LOADINGS AND WATER QUALITY IMPLICATIONS

Loading rates (g m^{-2} $year^{-1}$) for the four nutrients to the lakes and bays are presented in Tables 6.6 to 6.9. With respect to septic tank installations, current guidelines and policies for design relate to treatment of bacteria only. At present, no one really understands how effective this waste treatment practice is in preventing the translocation of nutrients to the water where coarse-textured, light soils overlay impervious bedrock. However, evidence is slowly appearing which reveals that conventional septic tank-tile field systems do not adequately contain nutrients. For example, Hall (1970) determined that the phosphorus fixation capacity of three Maine soil types (Adams, Plaisted and Paxton) would be exceeded if these soils were utilized as tile beds. The author stressed, ".....extreme care should be used on locating septic tank-drainfield waste water disposal systems adjacent to lakes or other surface waters that may be subjected to cultural eutrophication." Also, the same author confirmed that soils which allow for ".....the rapid passage of water through them are not as effective in removing phosphorus as those which present more of an obstruction to the passage of water..... the better the septic tank-drainfield system operates as a waste water disposal system, the poorer it operates as a means of protecting lake or groundwater waters from pollution elements". Finally, Hall confirmed that the freezing and thawing of the Adams soil (i.e. following the spring

freshet) were instrumental in leaching phosphorus initially retained by the soil..... from the drainfield areas to other areas such as the lake itself." Secondly, the Water Sub-Committee of the Natural Resources Committee of State Agencies for the State of Wisconsin in a report dated January 31, 1967 estimated that the phosphorus contribution reaching natural water courses from septic tank-tile field beds was 0.1 kg capita^{-1} year^{-1} (0.2 lbs capita^{-1} year^{-1}). Accordingly, it is recommended that research be conducted to establish whether existing specifications for septic tank-tile field installations are effective in preventing bacterial and nutrient contamination of surface waters. Additionally, alternative cottage waste treatment procedures should be evaluated for sites where conventional septic tank installations would not be expected to protect water quality.

Although carbon and reactive silica are important in influencing phytoplankton production and species composition, personnel involved in water management programmes have recently placed most emphasis on eliminating artificial point-sources of phosphorus and occasionally nitrogen from conventional sewage treatment systems as a means of improving water quality. In support of this philosophy Vollenweider (1968) predicted that the degree of eutrophication which could be produced by different annual loading rates of phosphorus and nitrogen was a logarithmic function of the mean depth of the lake. Thus, the rather classical approaches taken by Sawyer (1947) and others, of relating nutrient concentrations in solution at a given time to trophic state is less important than nutrients <u>supplied</u> to a lake - especially when assessing lake quality from a water management and eutrophication control point of view. Phosphorus loading rates to Lakes Joseph, Rosseau and Muskoka and the four selected Bays are presented in Figure 6.3 (after Vollenweider 1968). It should be recognized that a turnover time or flushing effect (years) has been incorporated into Figure 6.3 (Vollenweider, currently in press). Thus, lakes having a long turnover period would be more vulnerable to nutrient inputs than systems having rapid flushing periods - assuming basic morphometric similarities between the lakes. As indicated, loadings of phosphorus to Gravenhurst Bay exceeded the predicted "Dangerous Limit". Oligotrophic waters include those of Lakes Joseph, Rosseau, Little Joseph and Dudley Bay. Definite

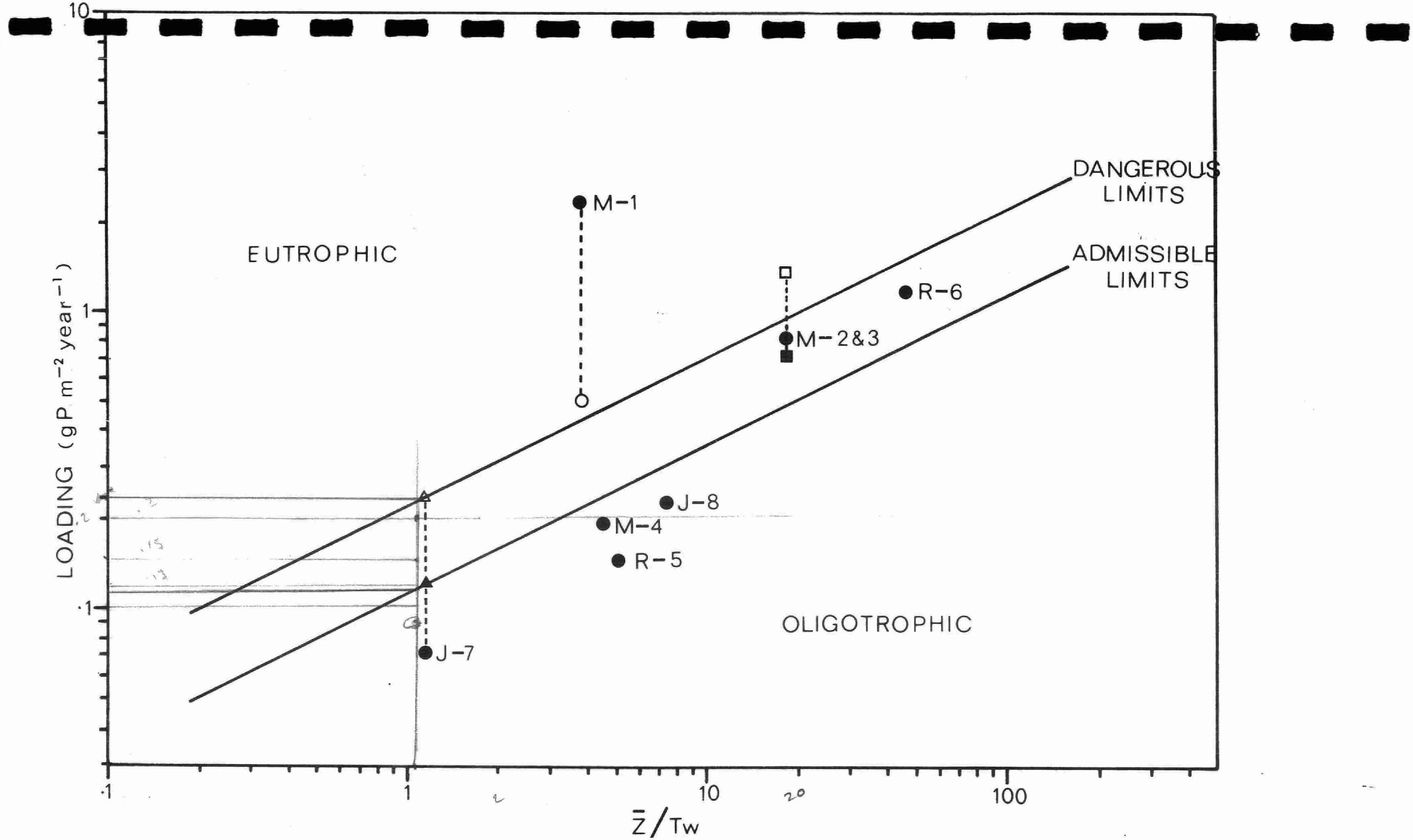

Figure 6.3: Annual total phosphorus loadings (closed circles) to Lakes Joseph (J-7), Rosseau (R-5) and Muskoka (M2 and M3), Dudley (M-4) and Gravenhurst (M-1) Bays and to Little Lake Joseph (J-8). Loading rates and clarification of the degrees of eutrophy (i.e. diagonal lines) are after Vollenweider (in press). Lakes above the upper diagonal are eutrophic in status while lakes below the lower diagonal are oligotrophic. Lakes between the diagonals are mesotrophic. The open circle represents the "measure of eutrophication" for Gravenhurst Bay following 85% reduction of phosphorus from the Gravenhurst and Ontario Hospital Sewage Treatment Plants. The closed and open triangles represent the positions of Lake Joseph following population increases of 1,150 and 4,400 capita-years, respectively. The open square depicts the eutrophic status of Muskoka Lake with twice the current population. The closed square represents a slightly improved trophic status in relation to the lake's present position assuming 85% phosphorus removal for the aforementioned increased population as well as for current shoreline residents.

concern must be expressed relative to the current near - "Dangerous" status of Lake Muskoka and Skeleton Bay. With respect to Lake Muskoka, for the first time on record, a short lived blue-green algal bloom materialized in October of 1971 over the entire surface of the lake - an initial indication of the somewhat tenuous nature of water quality in this lake. The mesotrophic status of Skeleton Bay is realistic owing to its relatively large watershed (142.5 km^2) area.

One aspect which must be considered when applying Vollenweider's model to relatively small, developed Precambrian lakes is that loadings calculated on the basis of per capita use (assuming no retention by soil septic systems) are extremely low relative to the quantity of algal material produced. For example, loadings to Lake Erie are 87 and 58 times greater than those computed for Riley Lake near Gravenhurst and for Little Lake Panache near Sudbury - two well-developed recreational lakes studied recently. Yet levels of algae are similar for the three lakes (see Michalski 1968a and 1968b, and Michalski and Robinson 1970. Brydges (1971) recognized this limitation and postulated that apparent insignificant yearly inputs of phosphorus from cottage waste disposal systems can be incorporated into a lake's iron-phosphorus re-cycling mechanism. In turn, the concentration of phosphorus magnifies to produce nuisance weed and algal conditions. Thus, while inputs in any one year may not be sufficient to create problems, over a number of years inputs will effect conditions of accelerated eutrophy. This "magnification concept" accounts for the lag between large-scale development of a lake and the onset of eutrophic symptoms. Usually, the smaller lakes are the first to develop symptoms of accelerated enrichment. However, as indicated earlier, a short-lived blue-green algal bloom developed in October on Lake Muskoka - a relatively large lake (49.5 km^2). The aforementioned facts pertaining to "net inputs", the extreme vulnerability of Precambrian soft-water lakes to apparently low inputs as well as data presented earlier in this chapter which indicate that only a few years are required with average cottage use to exceed the phosphorus retention capacity of tile-field soils strongly reveal that nutrients from artificial sources are largely responsible for creating problems of accelerated eutrophy in recreational lakes.

The application of Vollenweider's model is valuable if considered from a recuperative point of view. For example, an 85% reduction of phosphorus at the Gravenhurst and Ontario Hospital Sewage Treatment Plants would reduce the loadings to the Bay from 2.375 to 0.510 g P m^{-2} $year^{-1}$; predictively Gravenhurst Bay would reverse its status from a highly eutrophic to a near-mesotrophic system. Technological refinements for removing phosphorus in excess of 85% at the local sewage treatment plants as well as complete containment of cottage wastes would further improve water quality in the Bay.

It is also of interest to consider Figure 6.3 in terms of establishing a lake's optimum population density or cottage capacity. As indicated, the current phosphorus loading to Lake Joseph is 0.076 g m^{-2} $year^{-1}$. The oligotrophic or "Admissible" loading limit to the lake is approximately 0.110 g P $m^{-2}year^{-1}$ (lower diagonal) while the eutrophic or "Dangerous" rate is 0.210 g P m^{-2} $year^{-1}$ (upper diagonal). Assuming that cottage development will continue in future years, that conventional septic tank-tile field systems will prevail as the sole treatment for domestic wastes (i.e. that no more nutrients are removed in cottage disposal systems than in the average secondary waste treatment plant - 1.5 kg P $capita^{-1}$ $year^{-1}$) and that all upstream nutrient inputs remain constant, conservative estimates indicate that additional populations of 1,150 and 4,400 capita - years would effect "Admissible" and "Dangerous" limits, respectively.

For purposes of predicting possible changes in a number of key eutrophication parameters, the following concepts are advanced. Correlation coefficients were developed between phosphorus loadings and mean Secchi disc values, phosphorus loadings and mean chlorophyll a concentrations and phosphorus loadings and standing stocks of algae expressed as mean areal standard units ml^{-1} for the three main lakes and four bays (Figure 6.4a, b and c). All data refer to the study year of 1969. Phosphorus loading reductions from 2.370 to 0.515 g m^{-2} $year^{-1}$ (achieved through an 85% reduction at the local sewage treatment plants) should

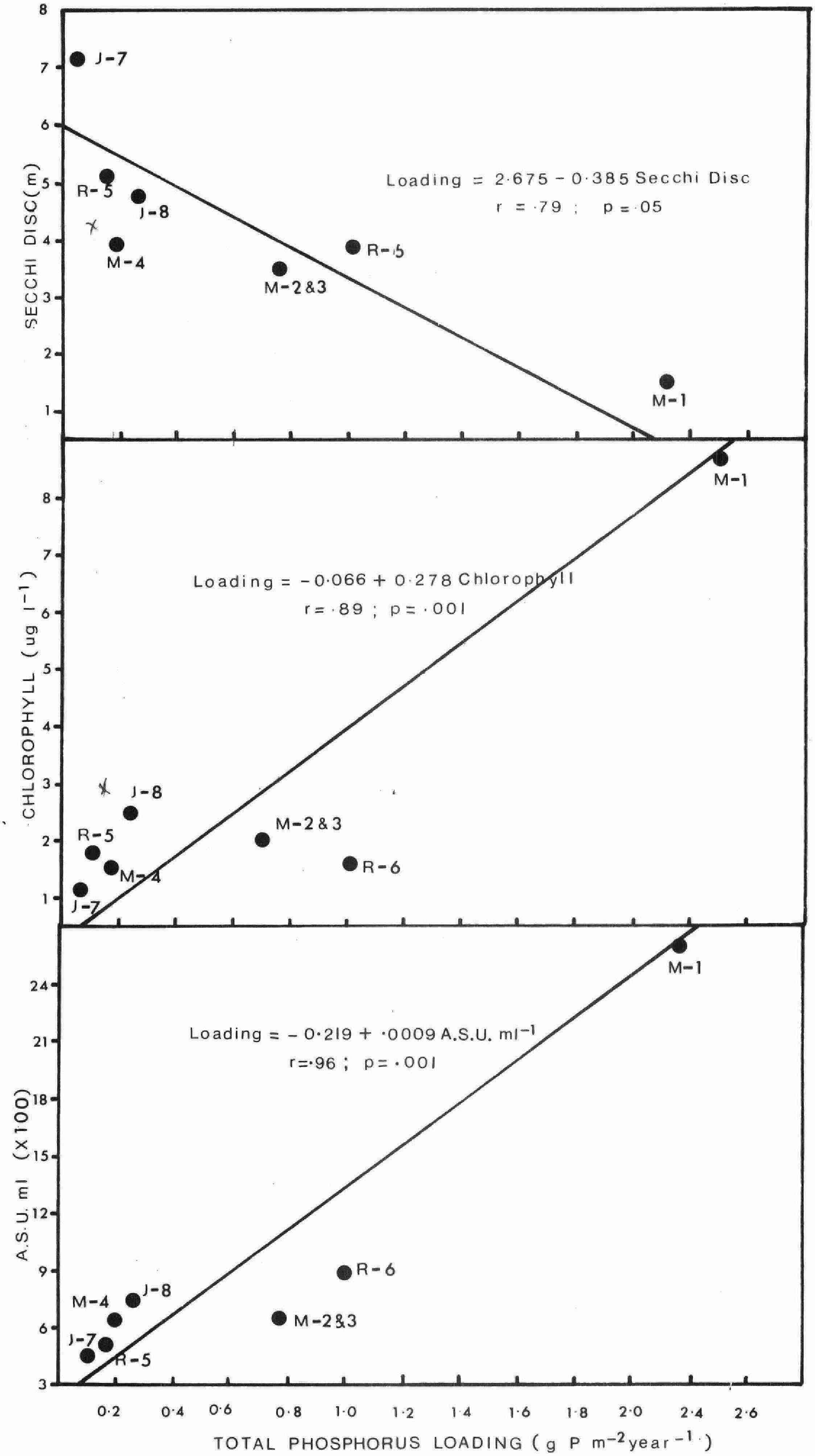

Figure 6.4: Relations between phosphorus loading and (a) mean summer Secchi disc visibilities (b) mean summer chlorophyll concentrations and (c) standing stocks of phytoplankton, at three main lakes and from bays in the study area.

improve Secchi disc visibility from 2.5 to 5.8m (Figure 6.4a). Additionally, chlorophyll a concentrations would decrease from 8.5 to 2.5 $\mu g\ l^{-1}$ while standing stocks of phytoplankton would be reduced from 2,500 to 850 a.s.u. ml^{-1}. On the other hand, if the population of Lake Muskoka doubles in future years (and assuming per capita, natural soil and upstream phosphorus contributions remain unchanged), the Lake would be effected by a loading of 1.211 g P m^{-2} $year^{-1}$ - an input nearly double the current loading effecting the system (0.747 g P m^{-2} $year^{-1}$). Correspondingly, one would expect the Secchi disc visibility to decrease from the present 5.0 to about 3.9 and chlorophyll a and phytoplankton stocks to increase to approximately 4.8 $\mu g\ l^{-1}$ and 1,500 a.s.u. ml^{-1}, respectively. The implementation or remedial measures to ensure 85% phosphorus removal for the increased population as well as for municipalities, resorts, cottagers and permanent shoreline residents currently discharging or leaching to the lakes would achieve a loading rate of 0.602 g P m^{-2} $year^{-1}$. It should be recognized that this estimate is slightly lower than the current loading to the system (0.747 g P m^{-2} $year^{-1}$). Significantly, water quality should be slightly improved over present conditions. With the aforementioned concepts in mind, personnel involved in water management programmes should recognize that water quality in Precambrian recreational lakes need not be impaired provided that domestic wastes are treated properly. Ongoing studies in the Muskoka Lakes area - particularly in Gravenhurst Bay where phosphorus removal at the local sewage treatment plant was initiated in 1971 - will indicate the validity of our predictions.

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APPENDIX A

Table 1a: Some climatic data for the Lake Muskoka area of southern Ontario in 1969. Air temperature and precipitation values are reproduced from Monthly Records, Canada Department of Transport at Milford Bay. Entries in centigrade for temperature and centimetres for precipitation are presented in the first line for each month, while the second line provides comparative data in Fahrenheit and inches. Solar radiation is expressed in langleys (g cal cm^{-2}).

Months	Air temperature				Solar radiation				Precipitation	
	Max. Temp.	Min. Temp.	Mean Monthly Max.	Mean Monthly Min.	Max. rad.	Min. rad.	Mean rad.	Total rad (x10)	Total Precip.	Total Precipitation from snow
January	7.2	-32.7	- 4.4	-15.6	-	-	-	-	11.6	94.7
	44.9	-26.8	24.0	3.9					4.5	37.2
February	5.5	-26.1	- 1.1	-13.7	-	-	-	-	2.4	24.3
	41.9	-14.9	30.0	7.3					0.9	9.5
March	10.5	-26.1	1.2	-10.8	-	-	-	-	5.8	10.1
	50.9	-14.9	34.1	12.5					2.3	3.9
April	21.1	-14.9	10.7	- 1.7	-	-	-	-	7.0	5.3
	69.9	5.18	51.2	28.9					2.7	2.0
May	26.6	- 4.9	16.7	1.9	741.3	93.4	435.5	16.2	10.4	0.5
	79.8	23.1	62.0	35.4					4.0	0.2
June	31.1	- 1.1	20.3	7.7	724.0	124.0	468.5	13.5	11.8	0.0
	87.9	30.0	68.5	45.8					4.6	0.0
July	31.6	1.6	25.1	10.2	738.0	213.0	570.8	17.6	3.7	0.0
	88.8	34.8	77.1	50.3					1.4	0.0
August	30.5	1.1	25.7	11.4	621.0	263.0	479.3	14.8	2.9	0.0
	86.9	33.9	78.2	52.5					1.1	0.0
September	28.3	- 1.6	19.3	7.7	515.0	142.0	308.6	9.2	7.0	0.0
	82.9	29.1	66.7	45.8					2.7	0.0
October	21.1	- 7.7	11.7	2.4	355.0	22.0	188.7	5.8	10.3	2.0
	69.9	18.14	53.0	36.3					4.0	0.8
November	14.9	-17.2	4.9	- 2.0	-	-	-	-	12.5	40.1
	58.8	1.0	40.8	28.4					4.9	15.8
December	3.8	-32.2	- 3.8	-13.4	-	-	-	-	4.6	44.1
	38.8	-25.9	25.1	7.8					1.8	17.3

Table 1b: Some climatic data for the Lake Muskoka area of southern Ontario in 1970. Air temperature and precipitation values are reproduced from Monthly Records, Canada Department of Transport at Milford Bay. Entries in centigrade for temperature and centimetres for precipitation are presented in the first line for each month, while the second line provides comparative data in Fahrenheit and inches. Solar radiation is presented in langleys (g cal cm^{-2}).

Months	Air Temperature				Solar Radiation				Precipitation	
	Max. Temp.	Min. Temp.	Mean Monthly Max.	Mean Monthly Min.	Max. rad.	Min. rad.	Mean. rad.	Total Rad ($x10^3$)	Total Precip.	Total Precip.
January	4.9	-36.1	- 7.7	-20.4	-	-	-	-	8.3	81.2
	41.0	-33.0	18.1	- 4.9					3.2	32.0
February	5.5	-36.1	- 3.9	-16.6	-	-	-	-	4.2	40.3
	42.0	-33.0	24.9	2.1					1.6	15.9
March	10.5	-24.9	1.8	-12.2	-	-	-	-	6.6	37.8
	51.0	-13.0	35.3	9.9					2.6	14.9
April	26.6	-13.8	11.3	- 3.4	-	-	-	-	7.7	30.9
	80.0	7.0	52.5	27.5					3.0	12.2
May	24.4	- 6.1	16.7	5.0	741.0	94.0	445.3	13.8	9.0	0.0
	76.0	21.0	62.1	41.1					3.5	0.0
June	28.3	0.5	22.7	8.1	756.0	74.0	543.6	16.3	7.2	0.0
	83.0	33.0	72.9	46.6					2.8	0.0
July	29.9	4.9	24.9	12.9	685.0	121.0	481.7	14.4	19.6	0.0
	86.0	41.0	76.9	55.3					7.7	0.0
August	30.5	3.3	24.1	11.2	617.0	159.0	497.6	15.4	3.2	0.0
	87.0	38.0	75.5	52.2					1.2	0.0
September	26.6	- 1.6	18.3	8.3	523.0	72.8	315.8	8.2	9.6	0.0
	80.0	29.0	65.0	47.1					3.8	0.0
October	24.9	- 7.2	14.0	3.1	-	-	-	-	11.3	0.0
	77.0	19.0	47.3	37.7					4.4	0.0
November	12.2	-14.4	5.7	- 1.9	-	-	-	-	5.9	28.2
	54.0	6.0	42.4	28.5					2.3	11.1
December	12.2	-28.3	- 4.1	-14.0	-	-	-	-	9.3	98.5
	54.0	-19.0	24.5	6.7					3.6	38.8

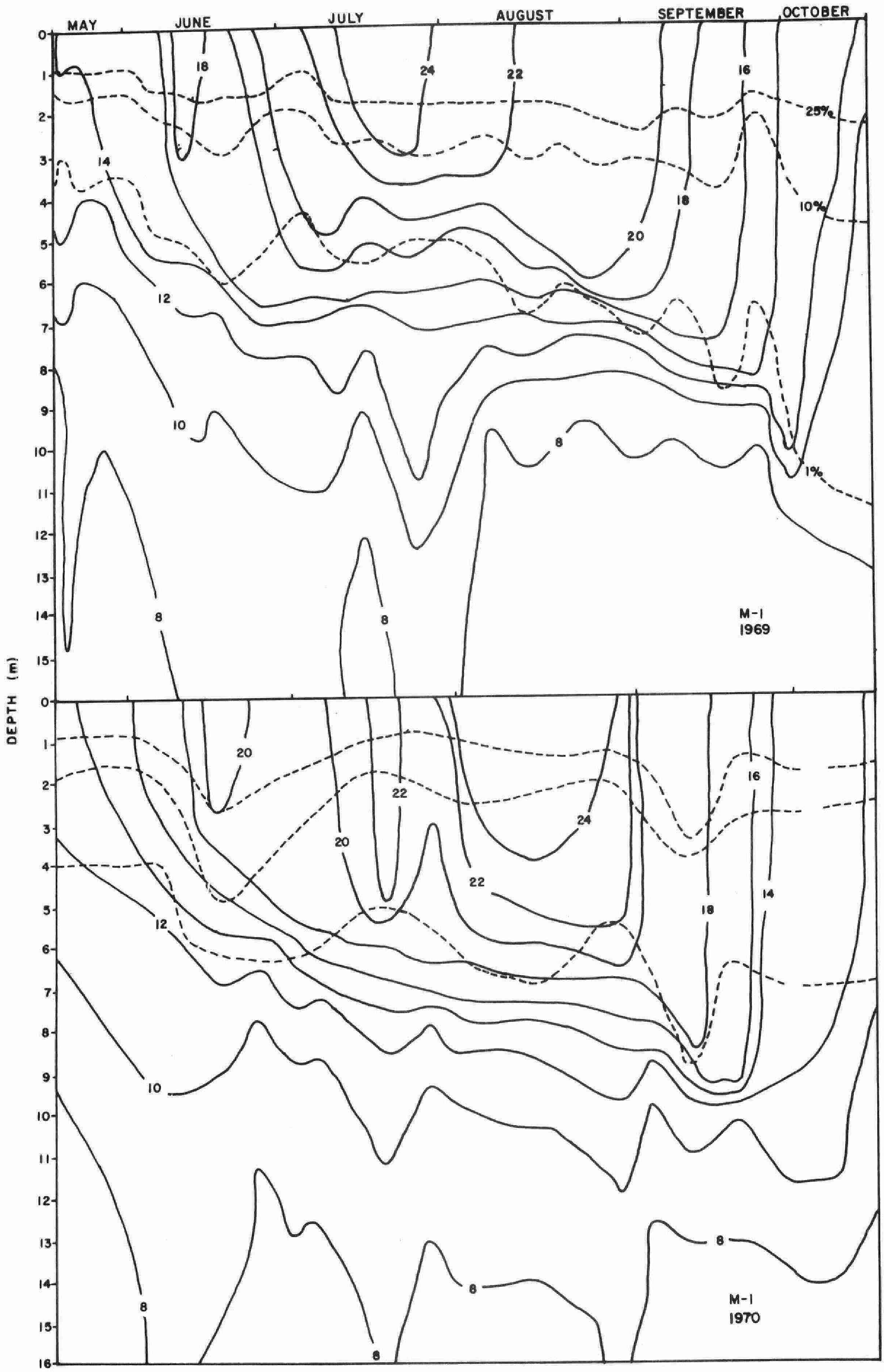

Fig. 1 Isotherms (solid lines) and isoplets (broken lines) at Station M-1 in Gravenhurst Bay determined by weekly samples in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

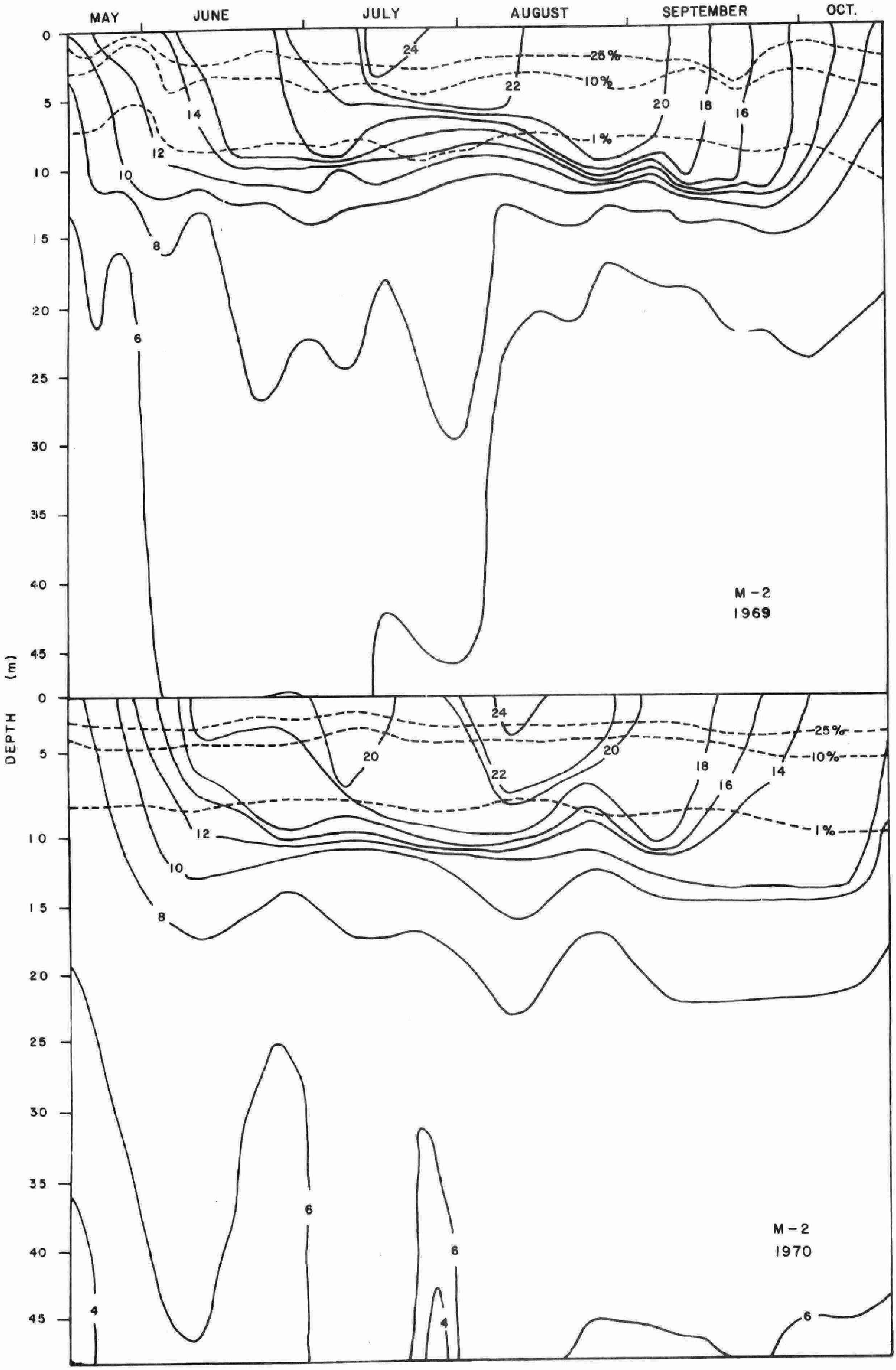

Fig. 2 Isotherms (solid lines) and isoplets (broken lines) at Station M-4 in Lake Muskoka determined by weekly sampling in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

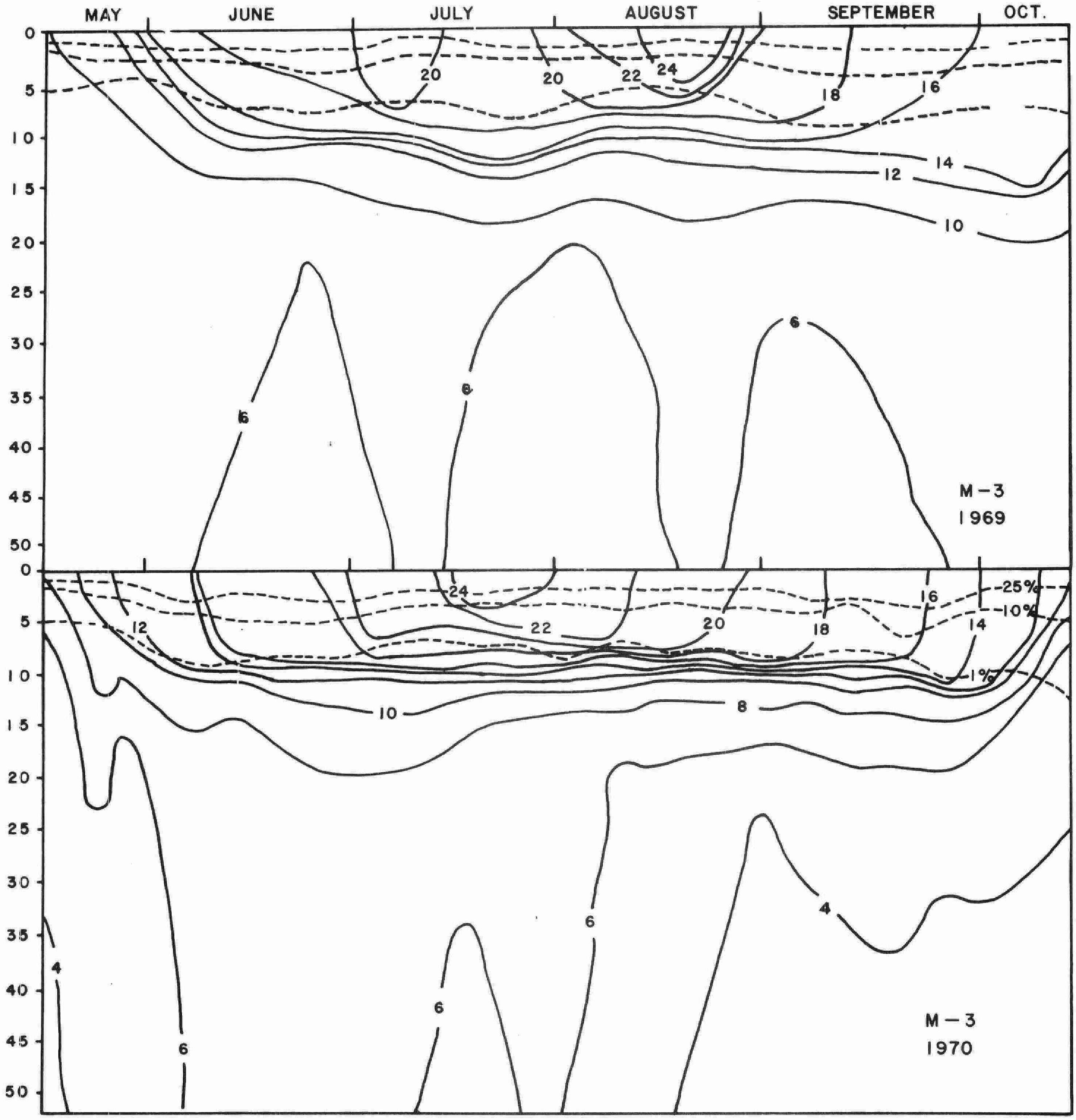

Fig. 3 Isotherms (solid lines) and isoplets (broken lines) at Station M-3 in Lake Muskoka determined by weekly sampling in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

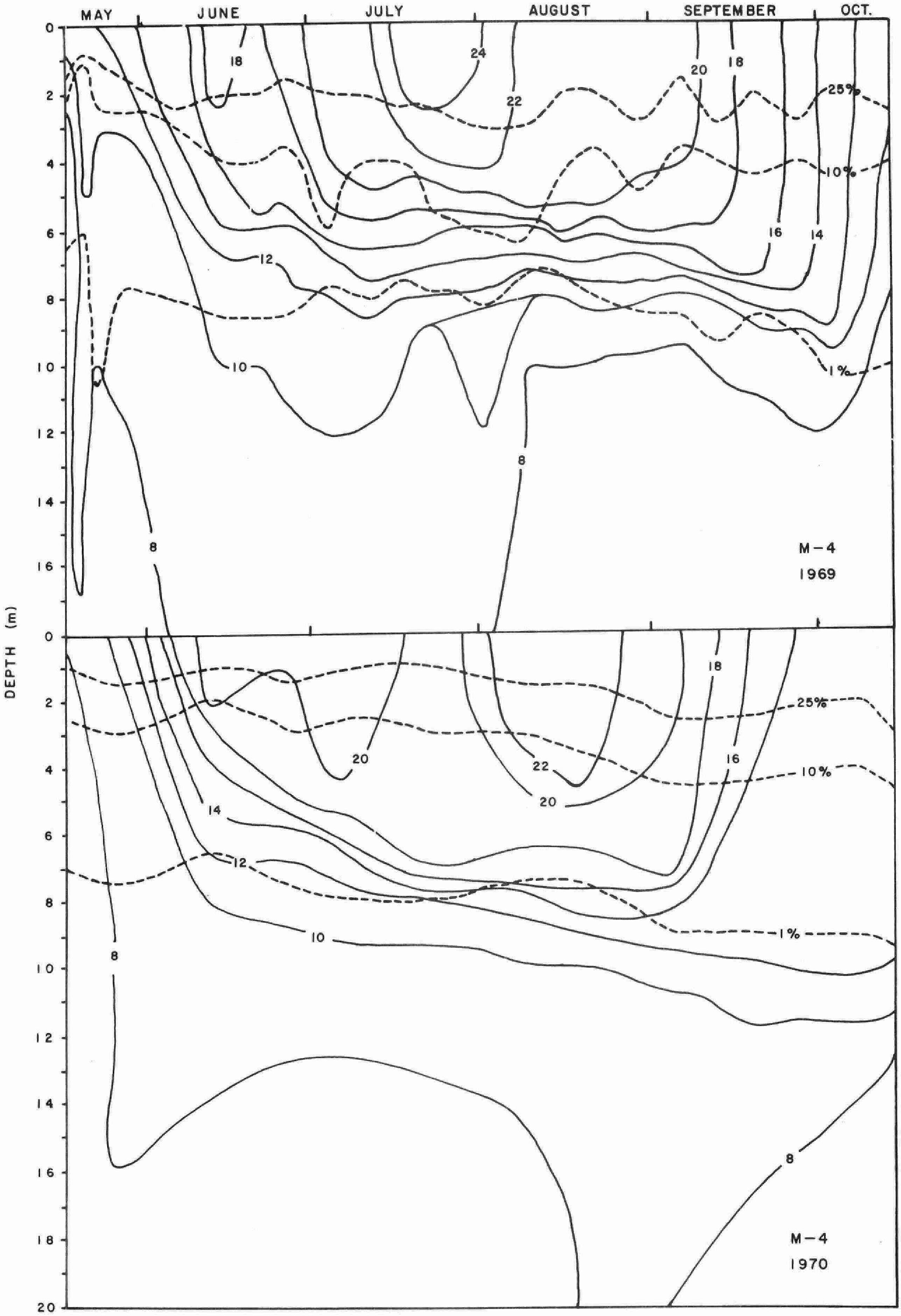

Fig. 4 Isotherms (solid lines) and isoplets (broken lines) at Station M-4 in Dudley Bay, Lake Muskoka determined by weekly sampling in 1969 (upper Panel) and twice monthly collections in 1970 (lower panel).

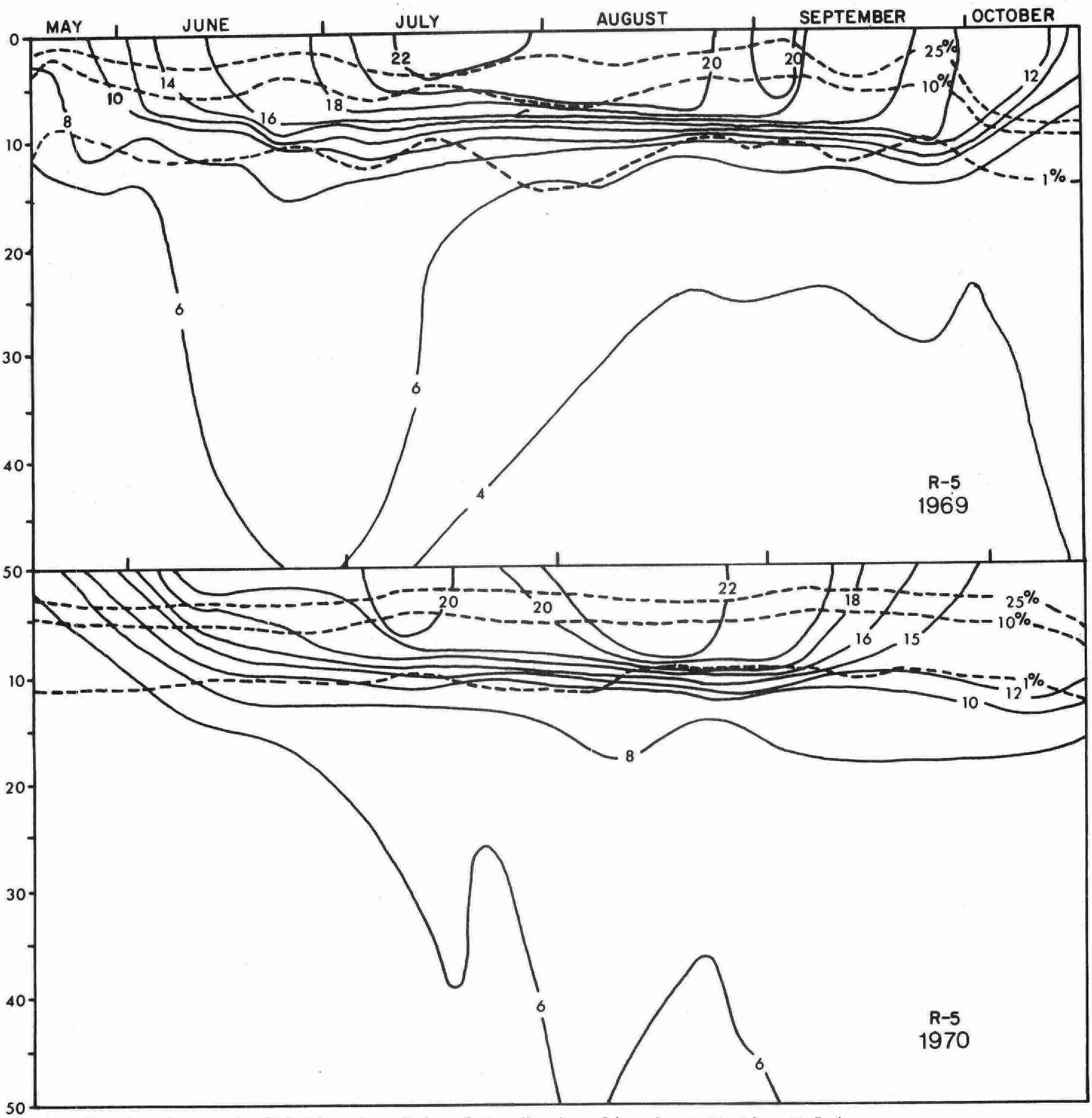

Fig. 5 Isotherms (solid lines) and isoplets (broken lines) at Station R-5 in Lake Rosseau determined by weekly samplings in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

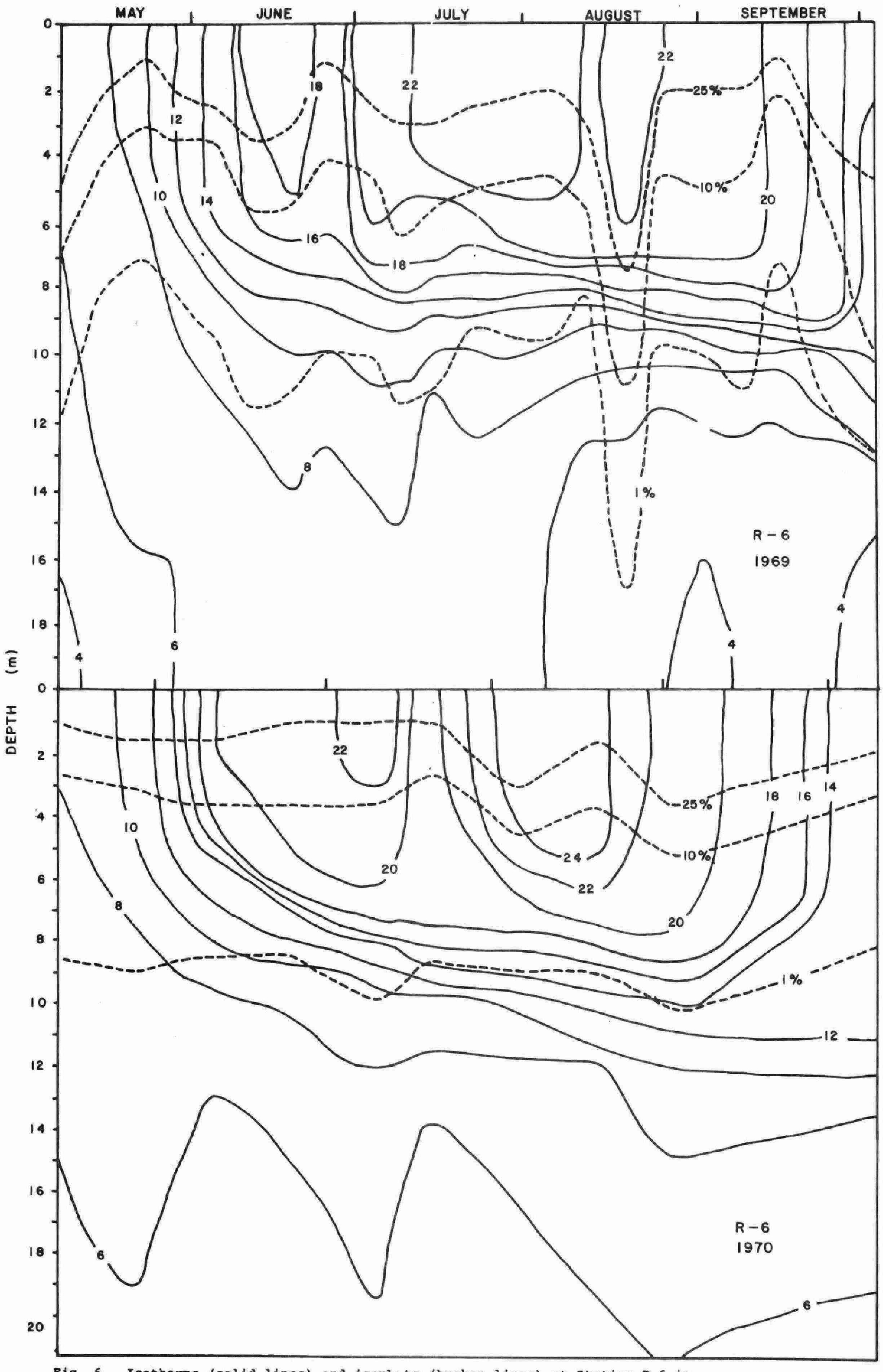

Fig. 6 Isotherms (solid lines) and isoplets (broken lines) at Station R-6 in Skeleton Bay of Lake Rosseau determined by weekly samplings in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

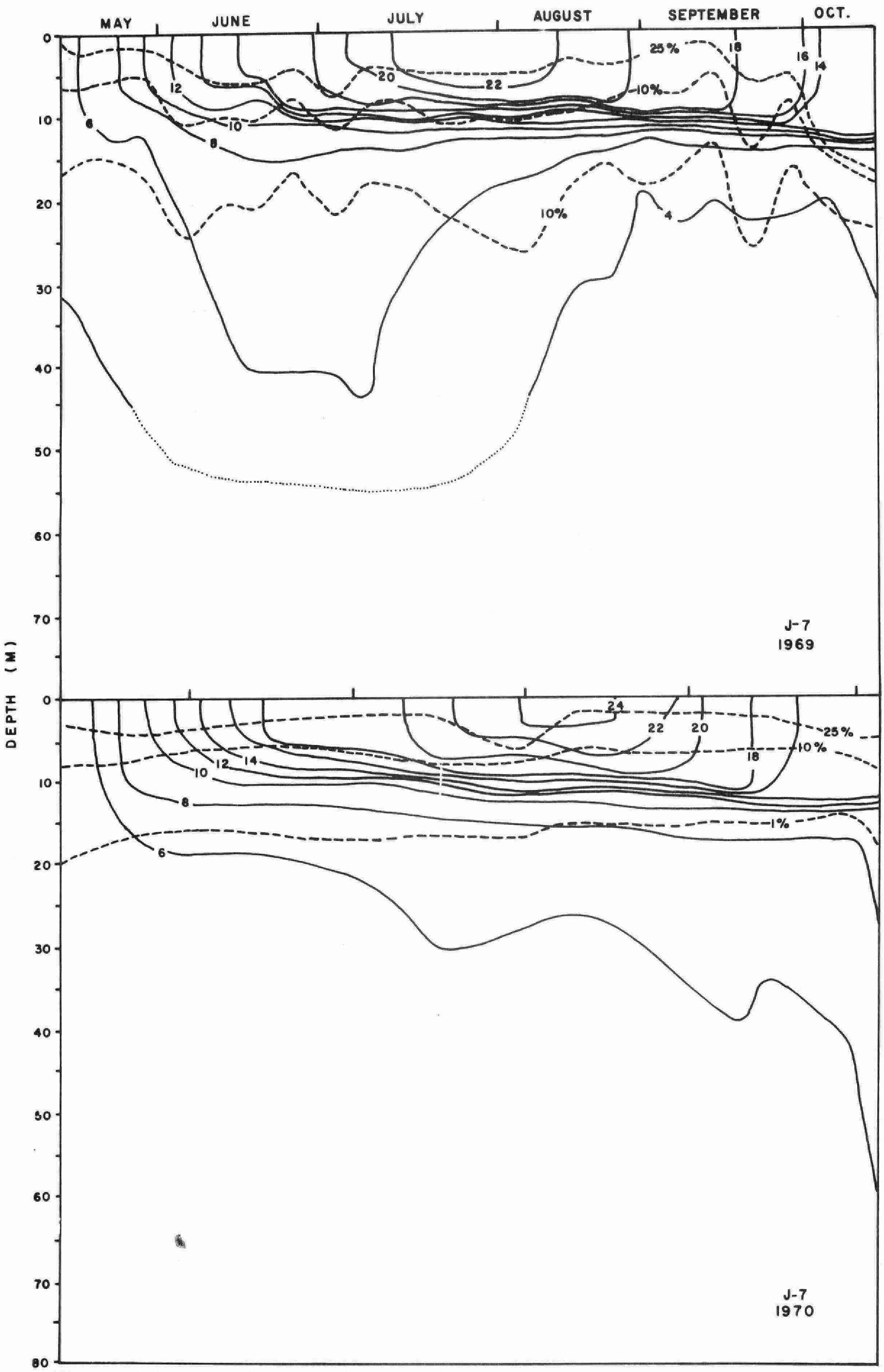

Fig. 7 Isotherms (solid lines) and isoplets (broken lines) at Station J-7 in Lake Joseph determined by weekly samplings in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

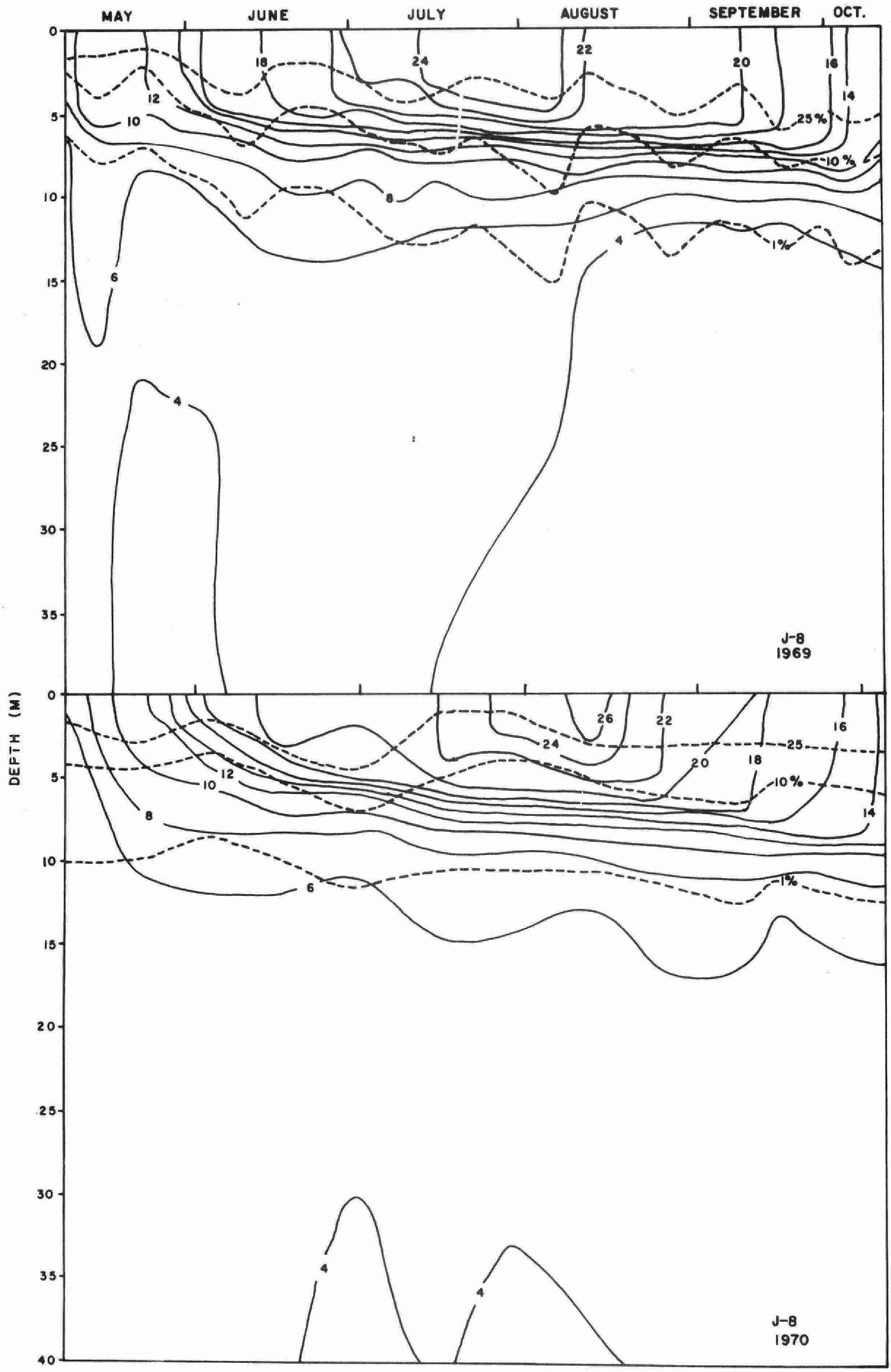

Fig. 8 Isotherms (solid lines) and isoplets (broken lines) at Station J-8 in Little Lake Joseph determined by weekly samplings in 1969 (upper panel) and twice monthly collections in 1970 (lower panel).

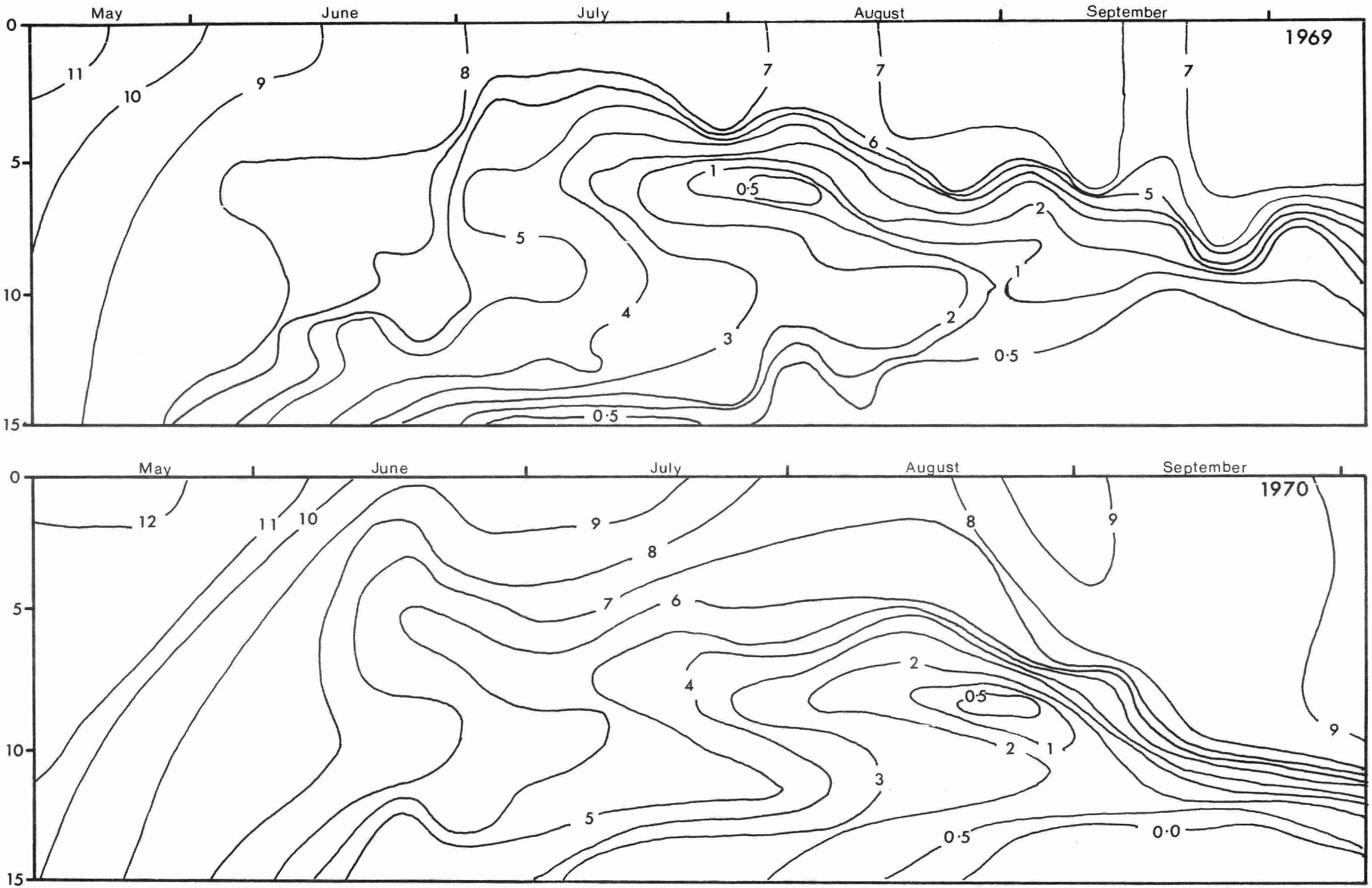

Figure 9: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station M-1 in 1969 and 1970.

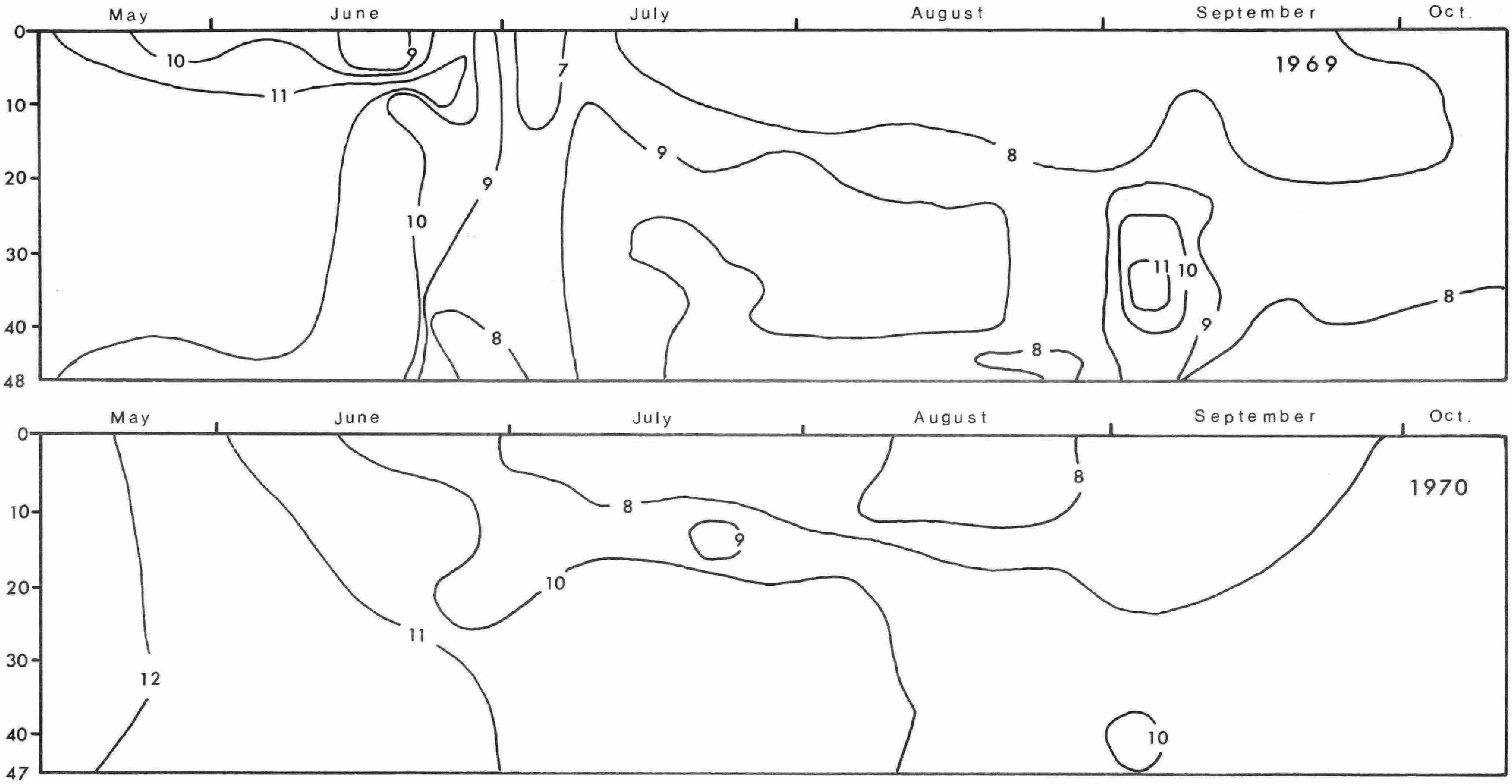

Figure 10: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station M-2 in 1969 and 1970.

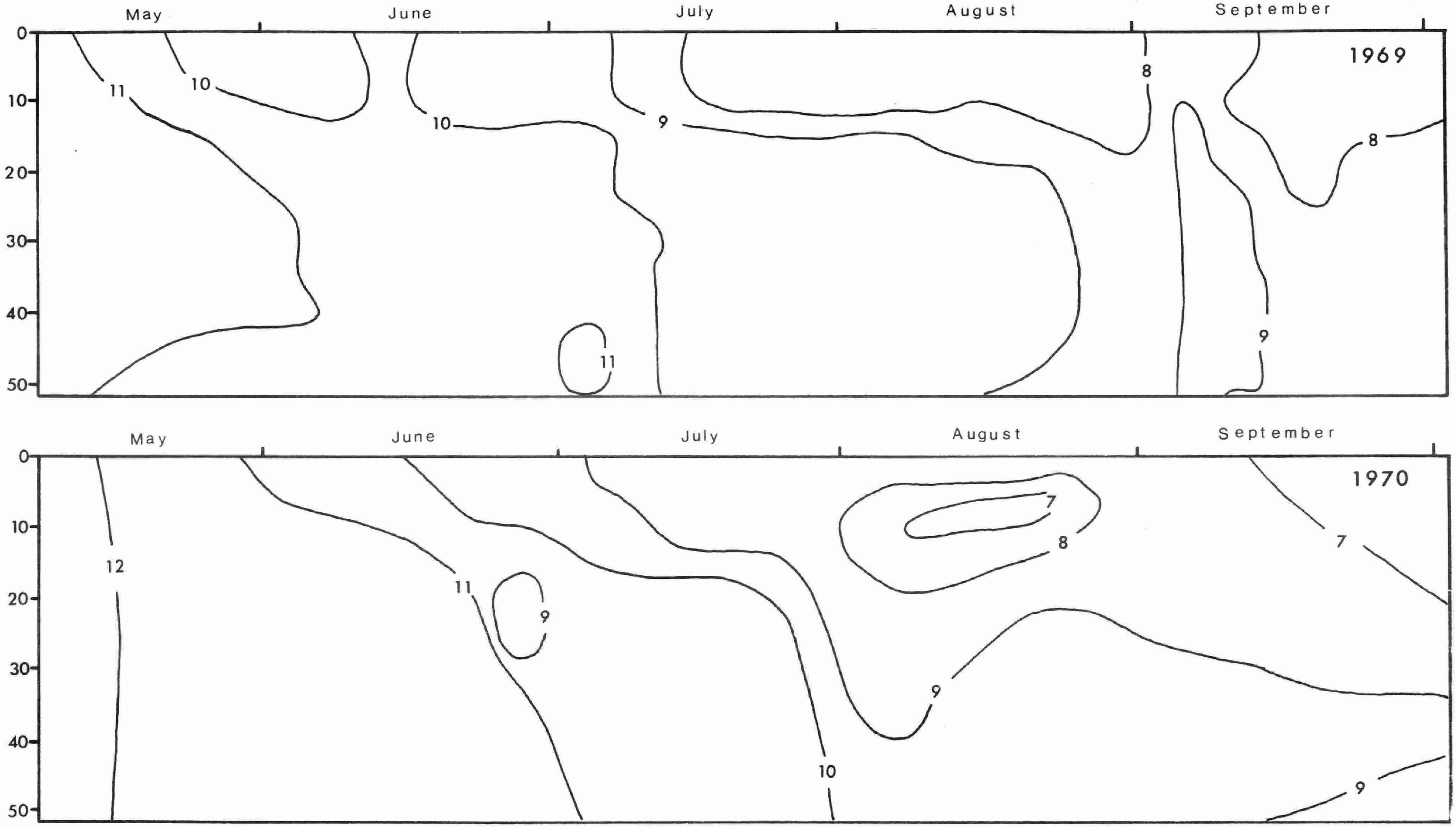

Figure 11: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station M-3 in 1969 and 1970.

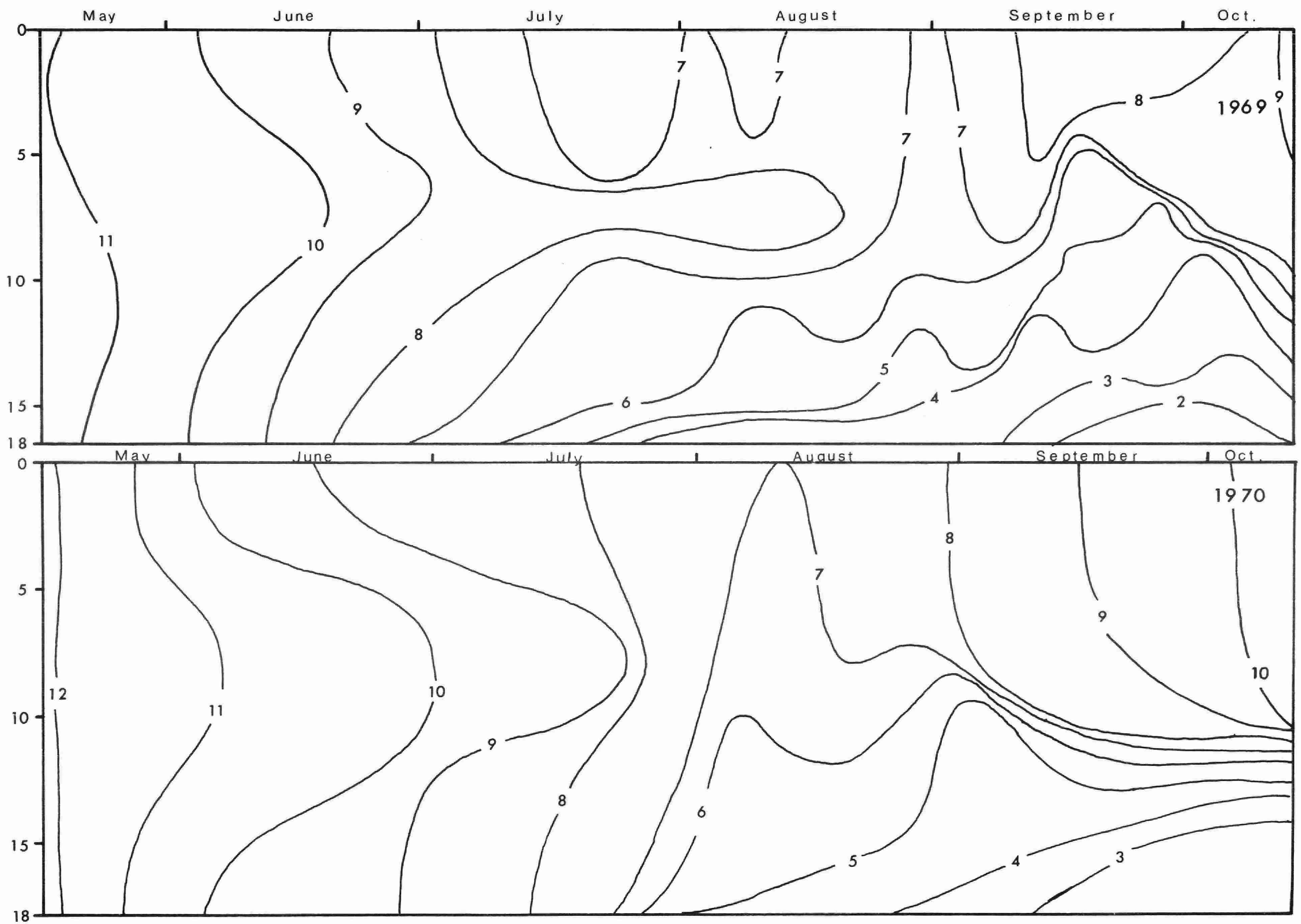

Figure 12: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station M-4 in 1969 and 1970.

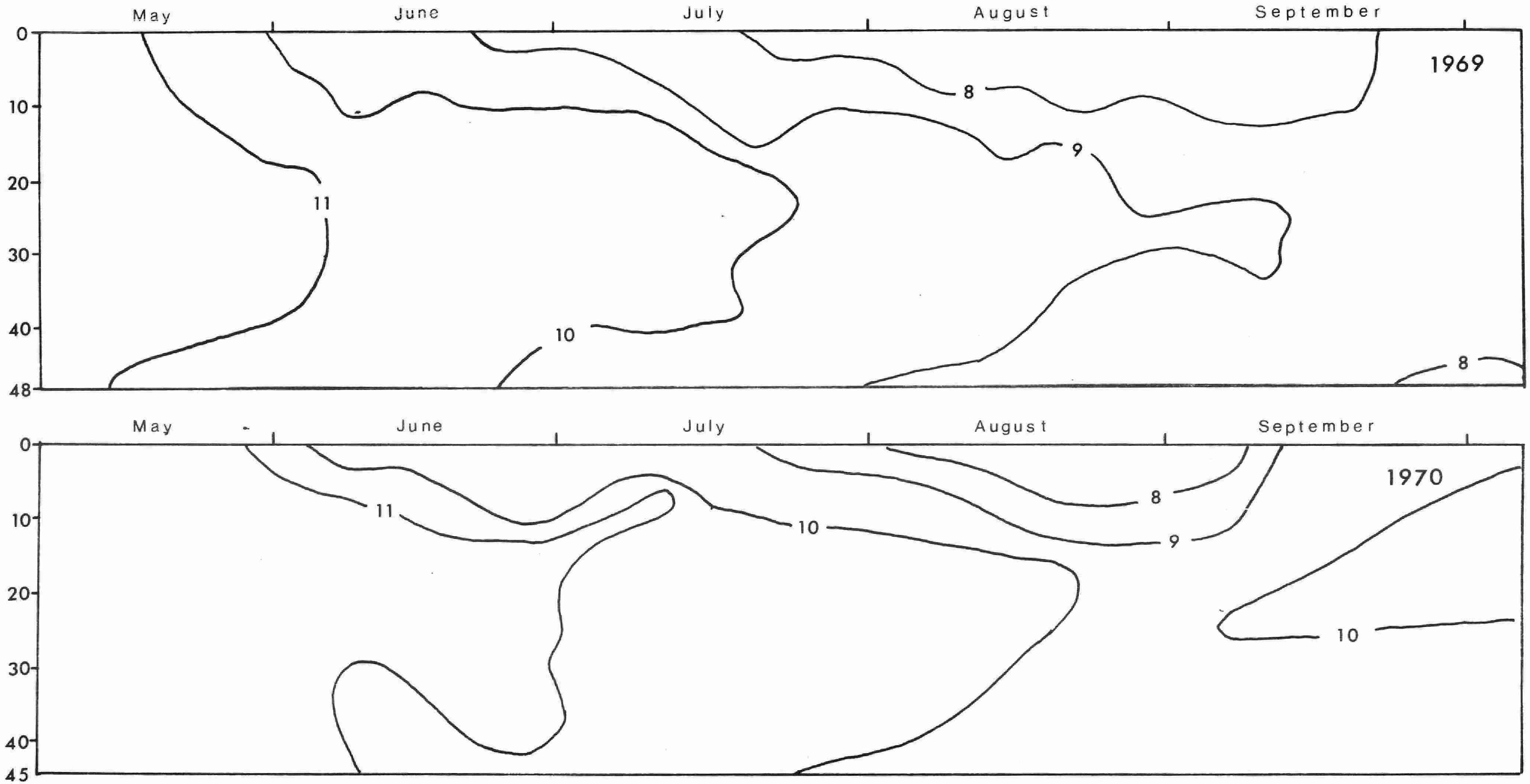

Figure 13: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station R-5 in 1969 and 1970.

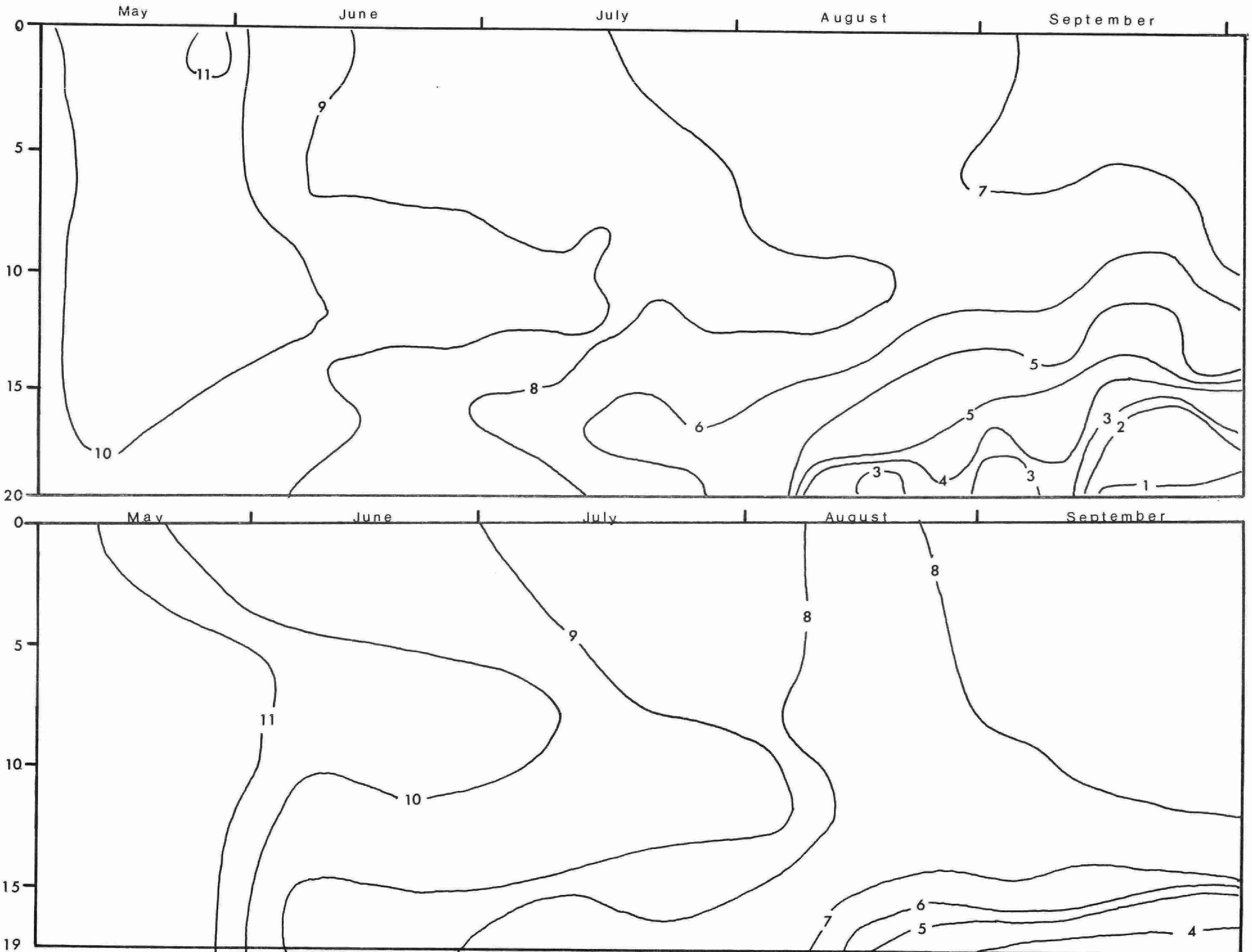

Figure 14: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station R-6 in 1969 and 1970.

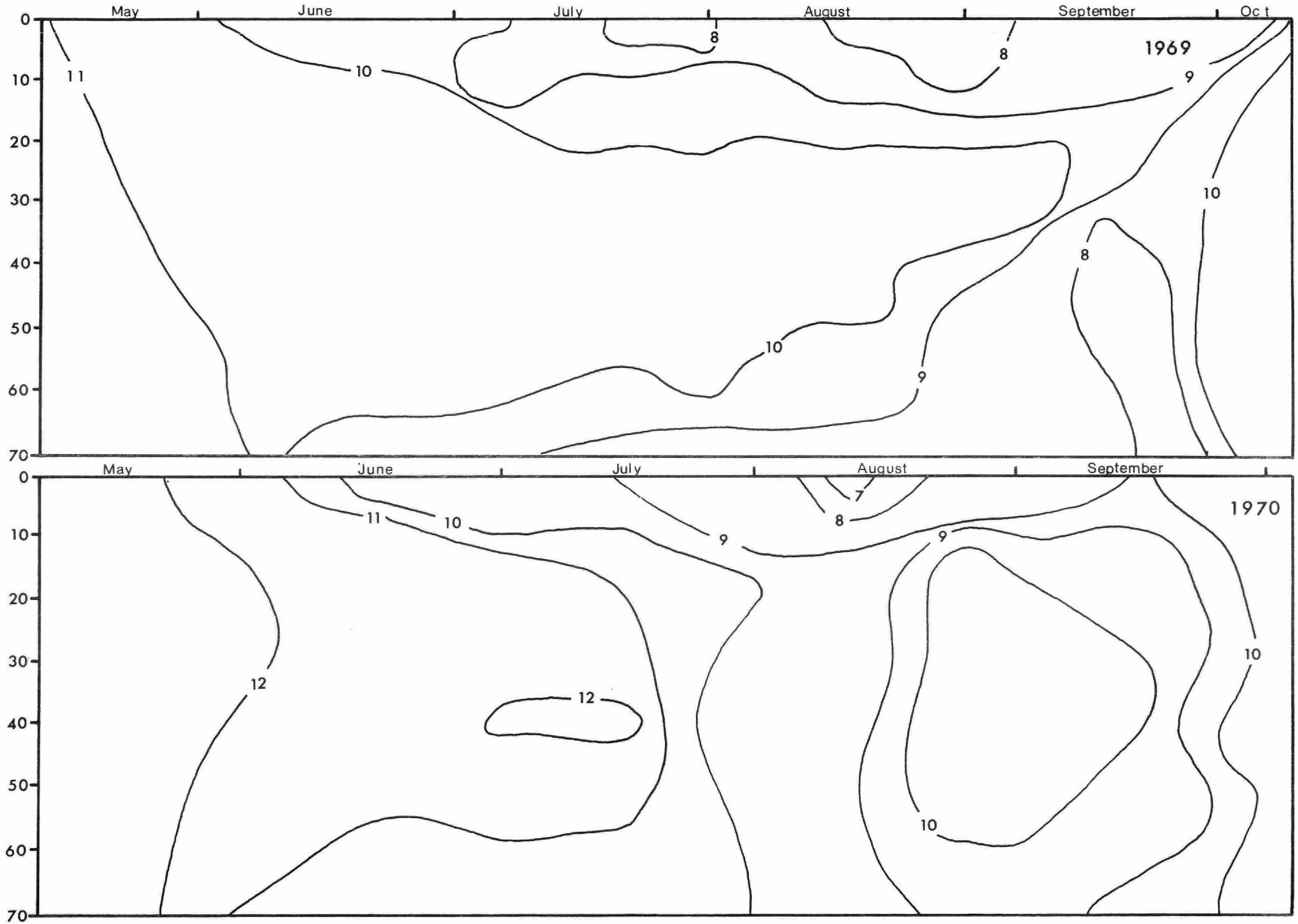

Figure 15: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station J-7 in 1969 and 1970.

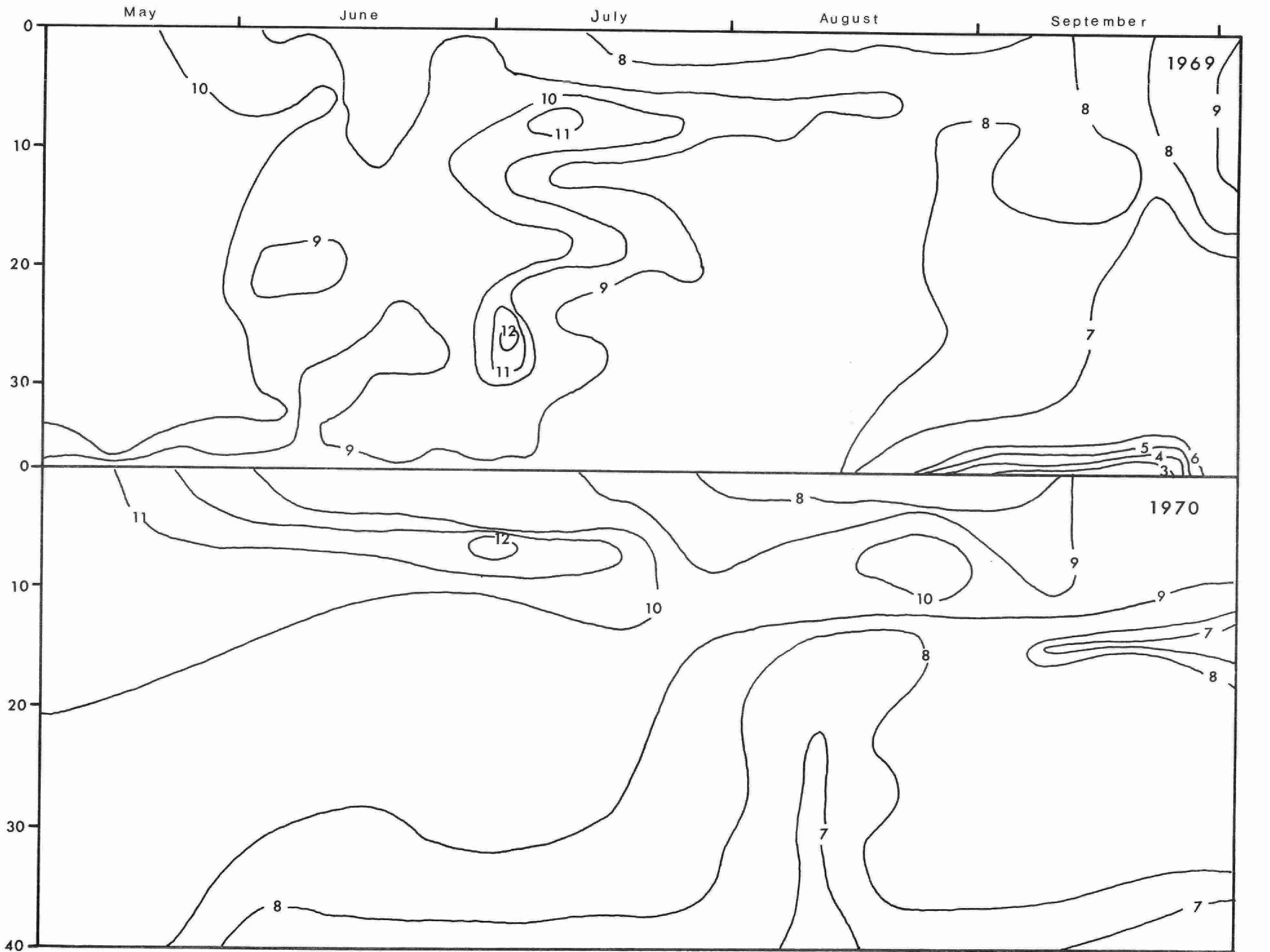

Figure 16: Seasonal isopleths of dissolved oxygen (mg l^{-1}) at Station J-8 in 1969 and 1970.

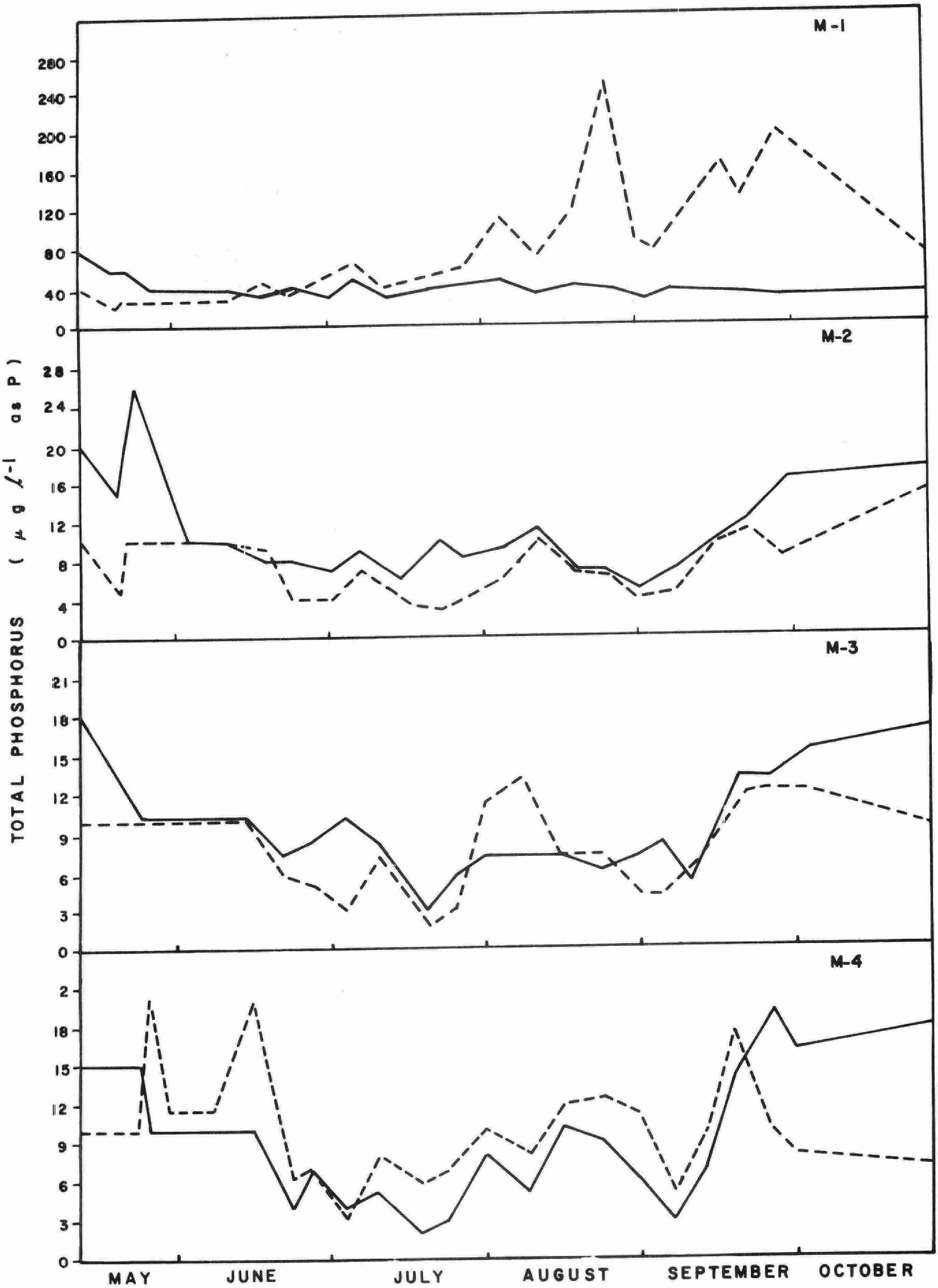

Fig. 17 Seasonal patterns for total phosphorus in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at Stations M-1 (Gravenhurst Bay), M-2 (Lake Muskoka), M-3 (Lake Muskoka) and M-4 (Dudley Bay) during the ice-free period of 1969.

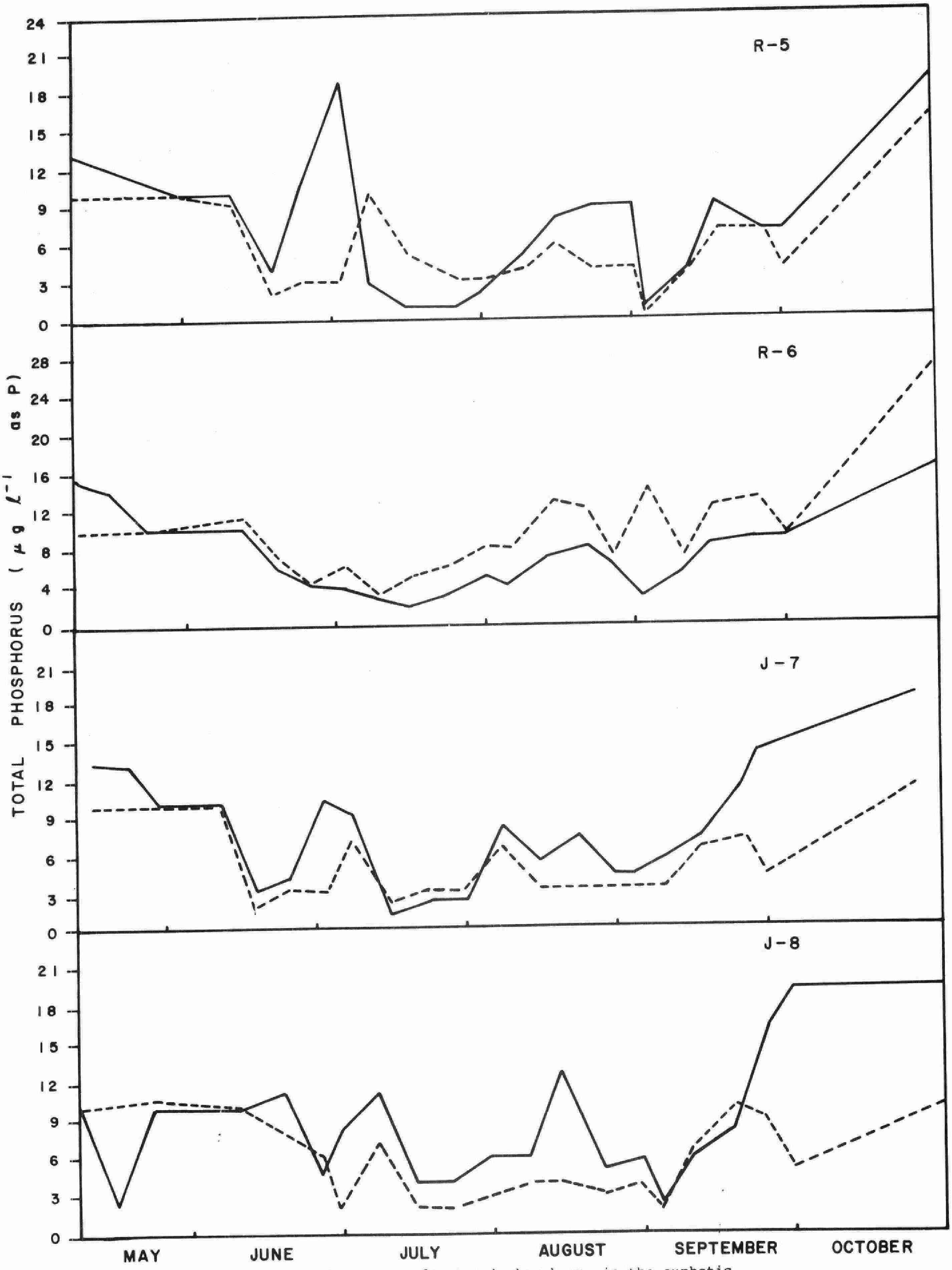

Fig. 17 (continued) Seasonal patterns for total phosphorus in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at Stations R-5 (Lake Rosseau), R-6 (Skeleton Bay), J-7 (Lake Joseph) and J-8 (Little Lake Joseph) during the ice-free period of 1969.

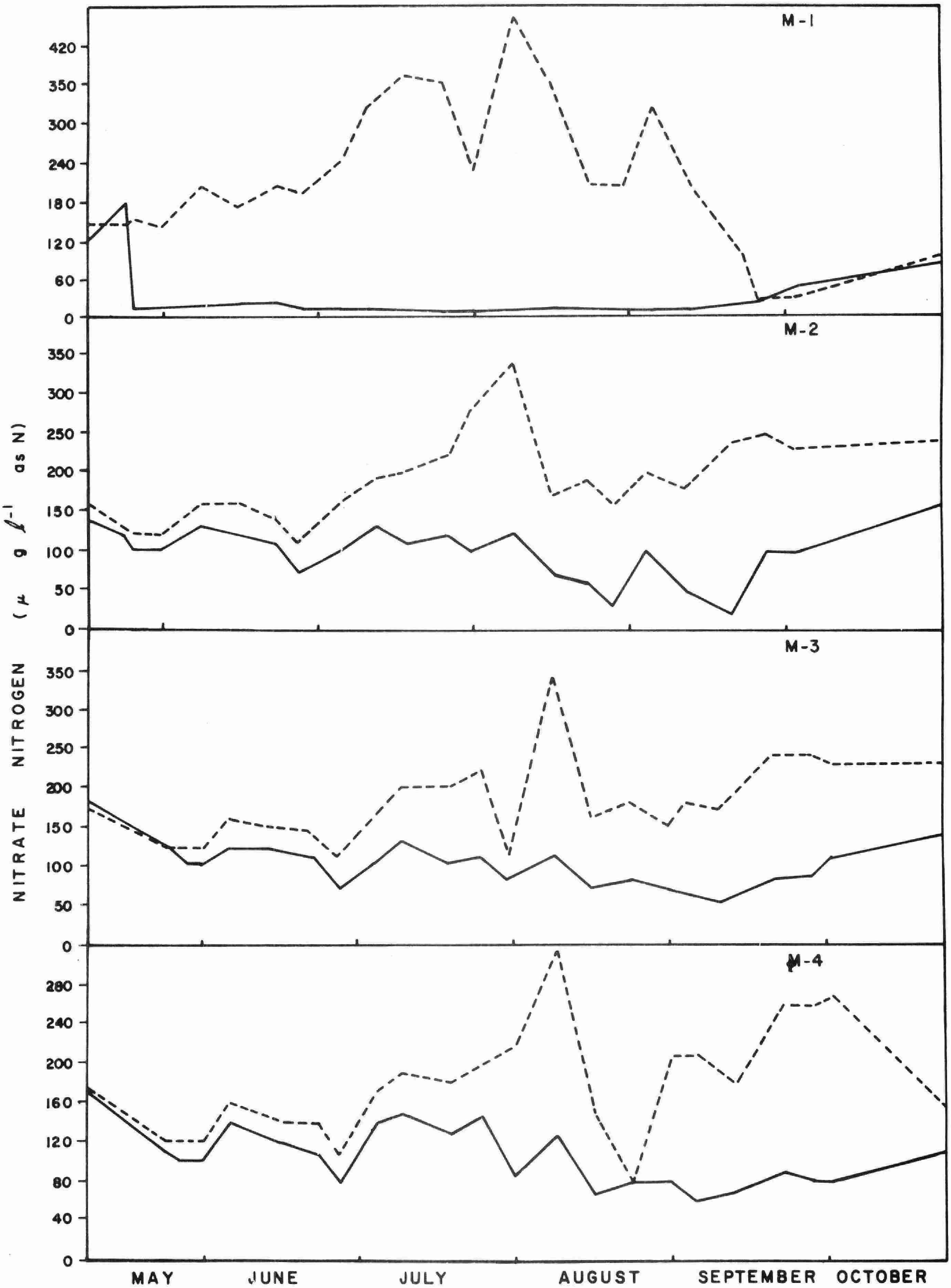

Fig. 18 Seasonal patterns for nitrate nitrogen in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at Stations M-1 (Gravenhurst Bay), M-2 (Lake Muskoka), M-3 (Lake Muskoka) and M-4 (Dudley Bay) during the ice-free period of 1969.

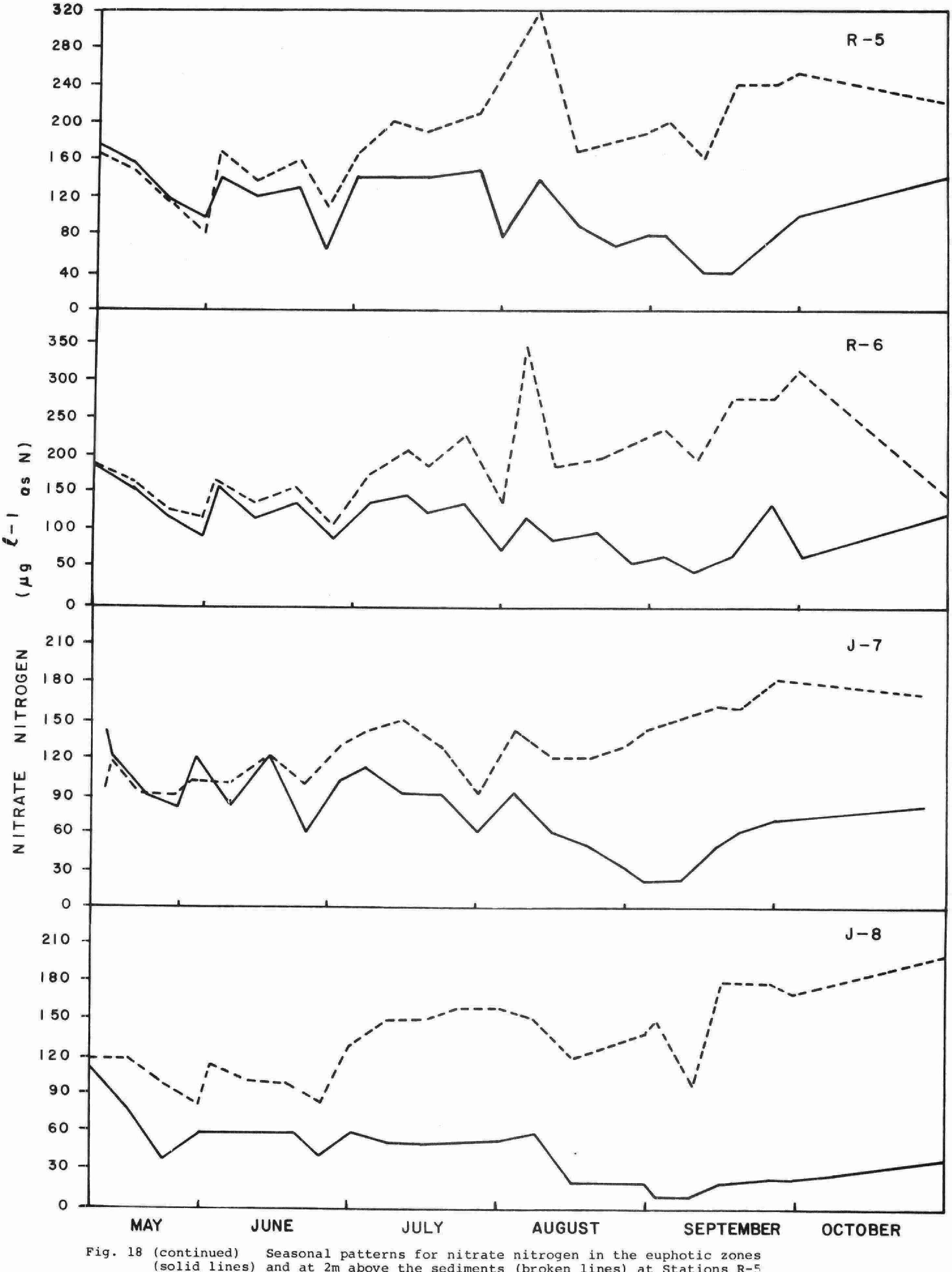

Fig. 18 (continued) Seasonal patterns for nitrate nitrogen in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at Stations R-5 (Lake Rosseau), R-6 (Skeleton Bay), J-7 (Lake Joseph) and J-8 (Little Lake Joseph) during the ice-free period of 1969.

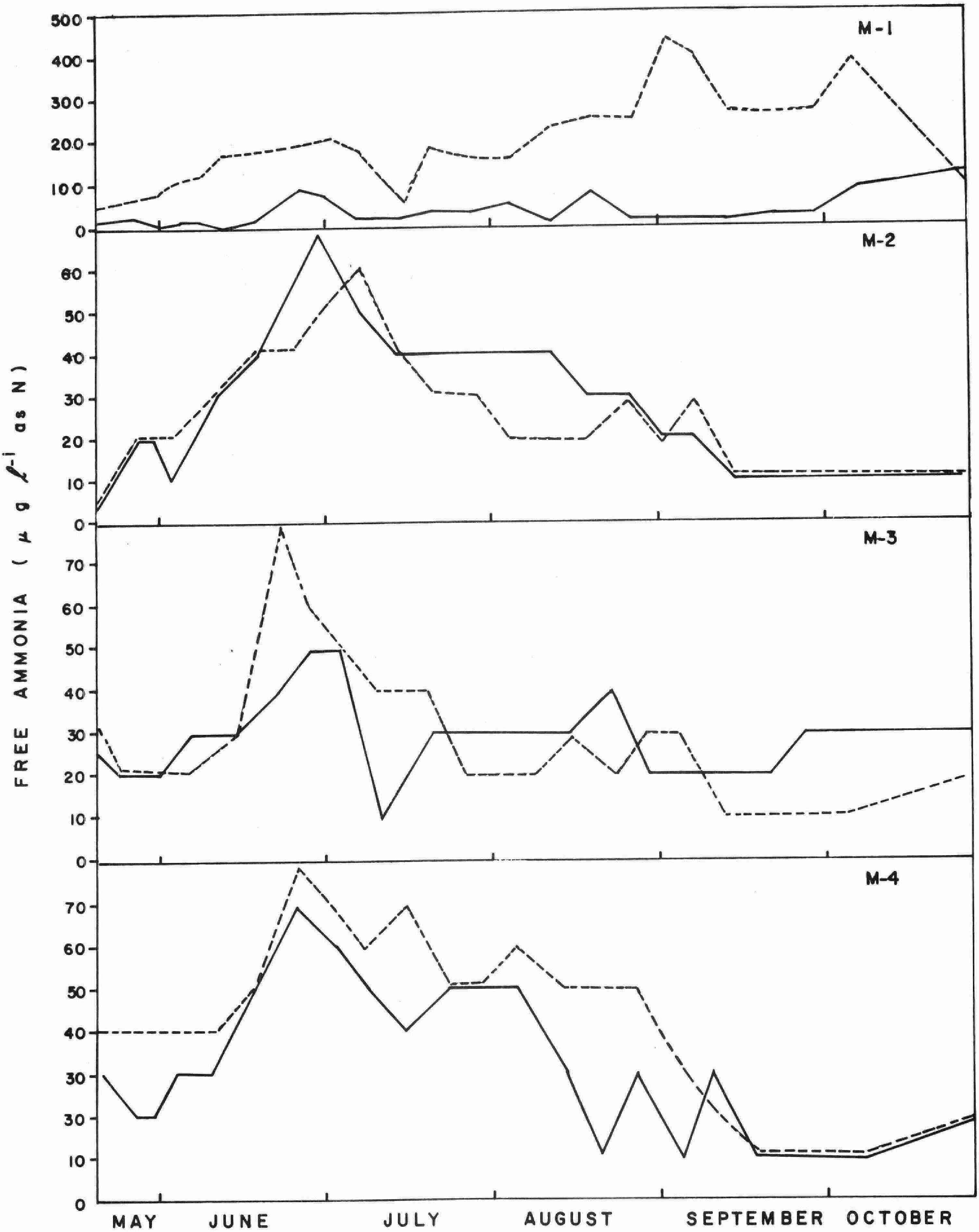

Fig. 19 Seasonal patterns for free ammonia in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at Stations M-1 (Gravenhurst Bay), M-2 (Lake Muskoka), M-3 (Lake Muskoka) and M-4 (Dudley Bay) during the ice-free period of 1969.

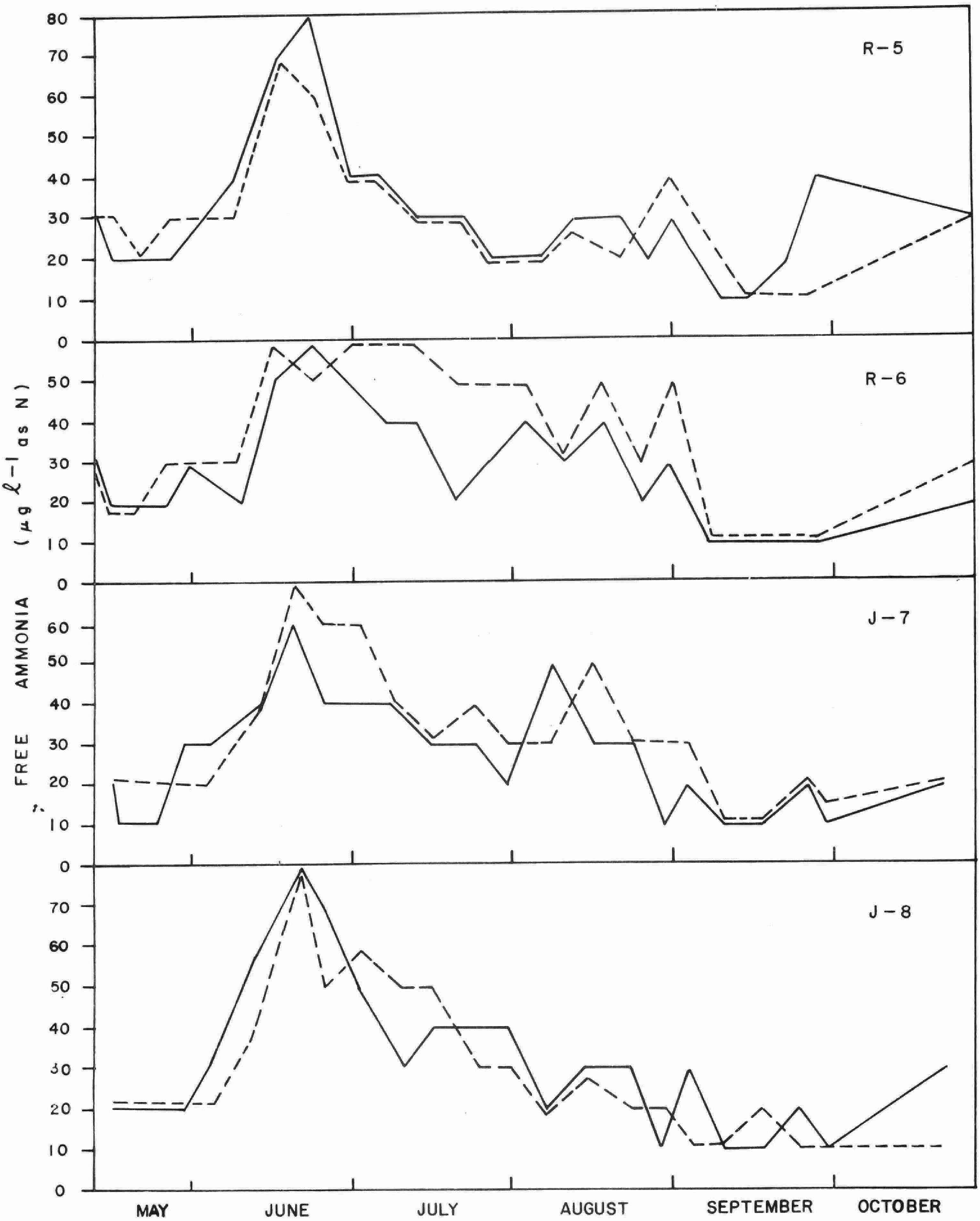

Fig. 19 (continued) Seasonal patterns for the ammonia in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at Stations R-5 (Lake Rosseau), R-6 (Skeleton Bay, J-7 (Lake Joseph) and J 8 (Little Lake Joseph) during the ice-free period of 1969.

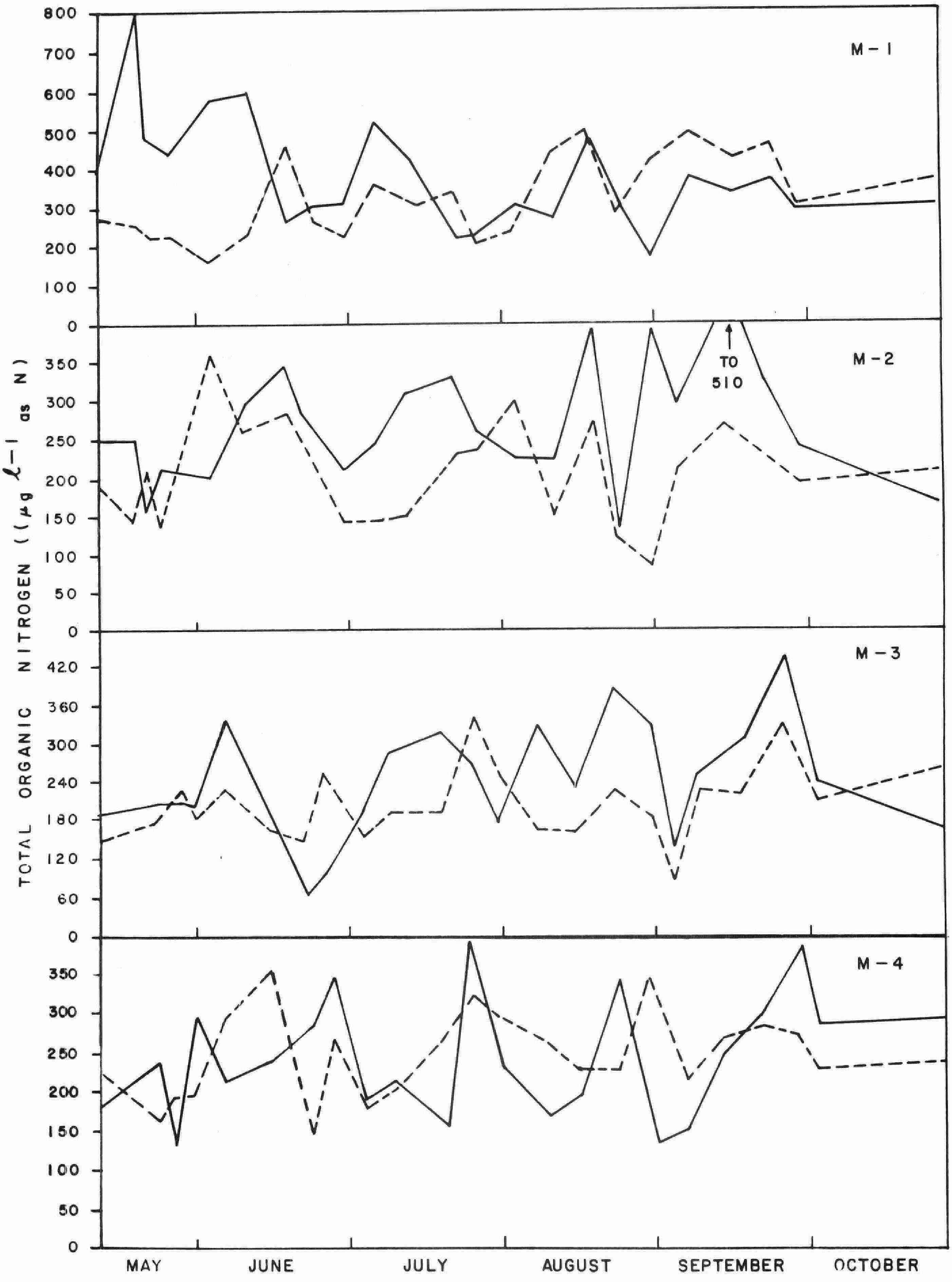

Fig. 20 Seasonal patterns for total organic nitrogen in the euphotic zones (solid lines) and at 2m above bottom (broken lines) at Stations M-1 (Gravenhurst Bay), M-2 (Lake Muskoka), M-3 (Lake Muskoka) and M-4 (Dudley Bay) during the ice-free period of 1969.

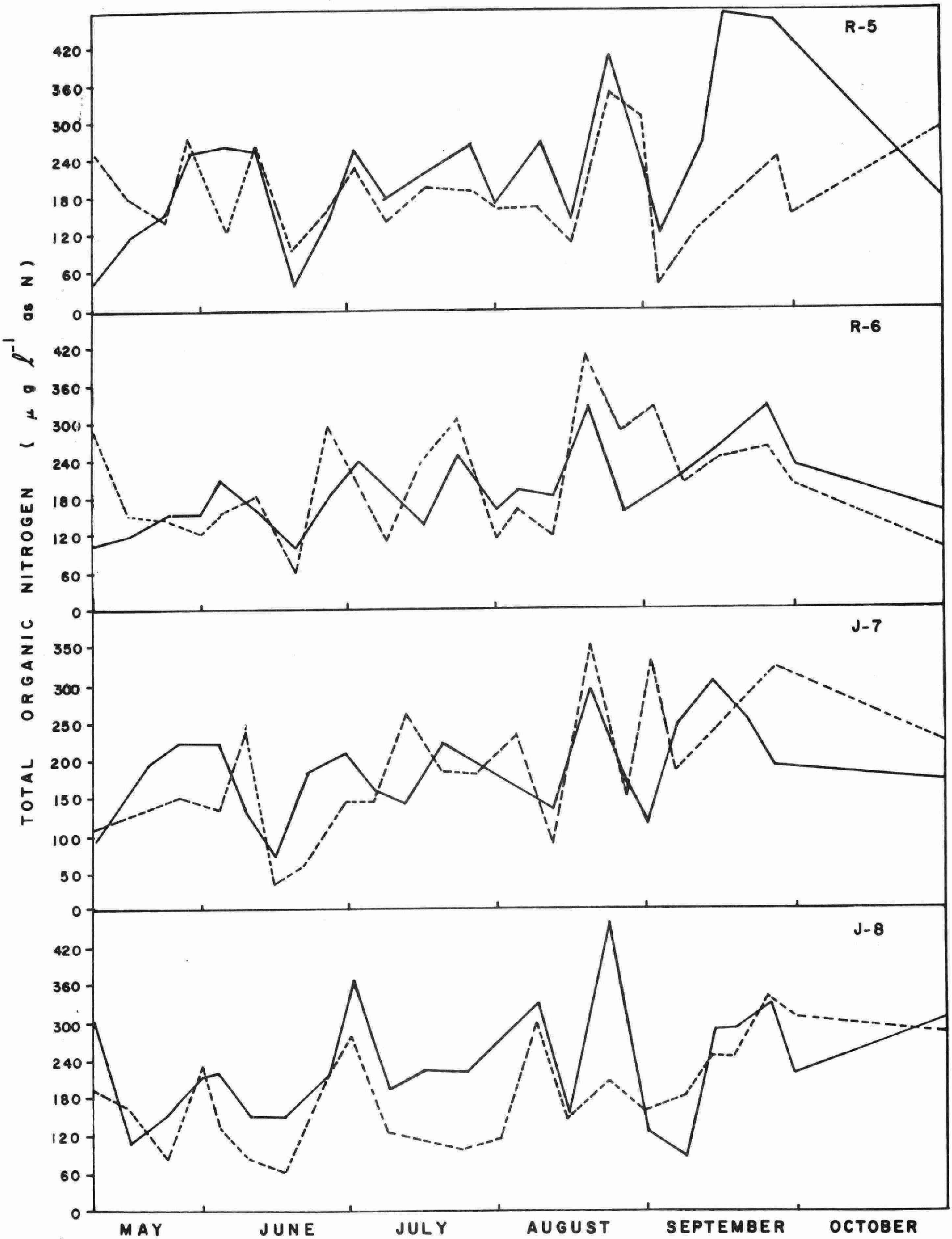

Fig. 20 (continued) Seasonal patterns for total organic nitrogen in the euphotic zone (solid lines) and at 2m above bottom (broken lines) at Stations R-5 (Lake Rosseau), R-6 (Skeleton Bay), J-7 (Lake Joseph) and J-8 (Little Lake Joseph) during the ice-free period of 1969.

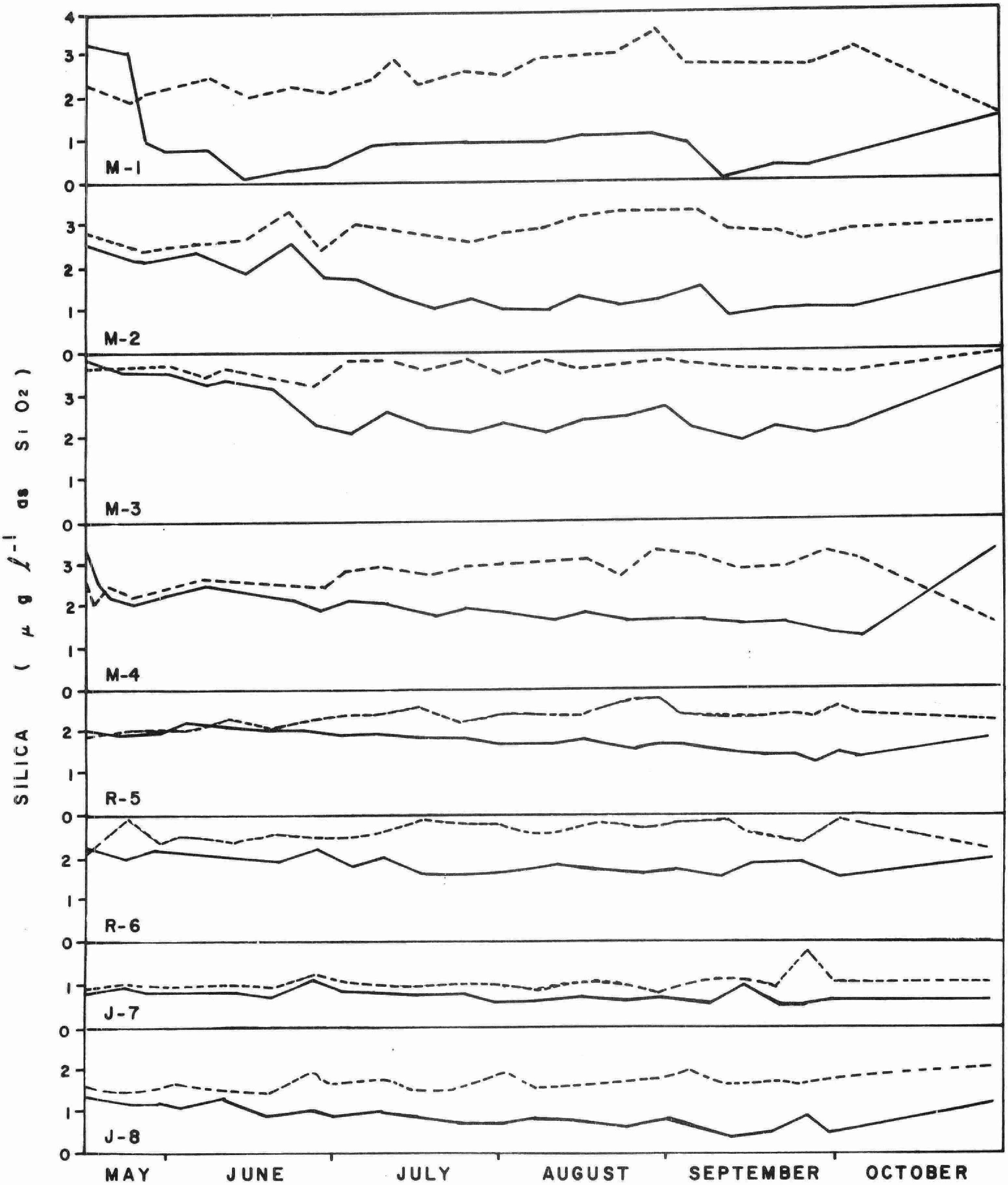

Fig. 21 Seasonal patterns for silica in the euphotic zones (solid lines) and at 2m above the sediments (broken lines) at eight stations in the study area during the ice-free period of 1969.

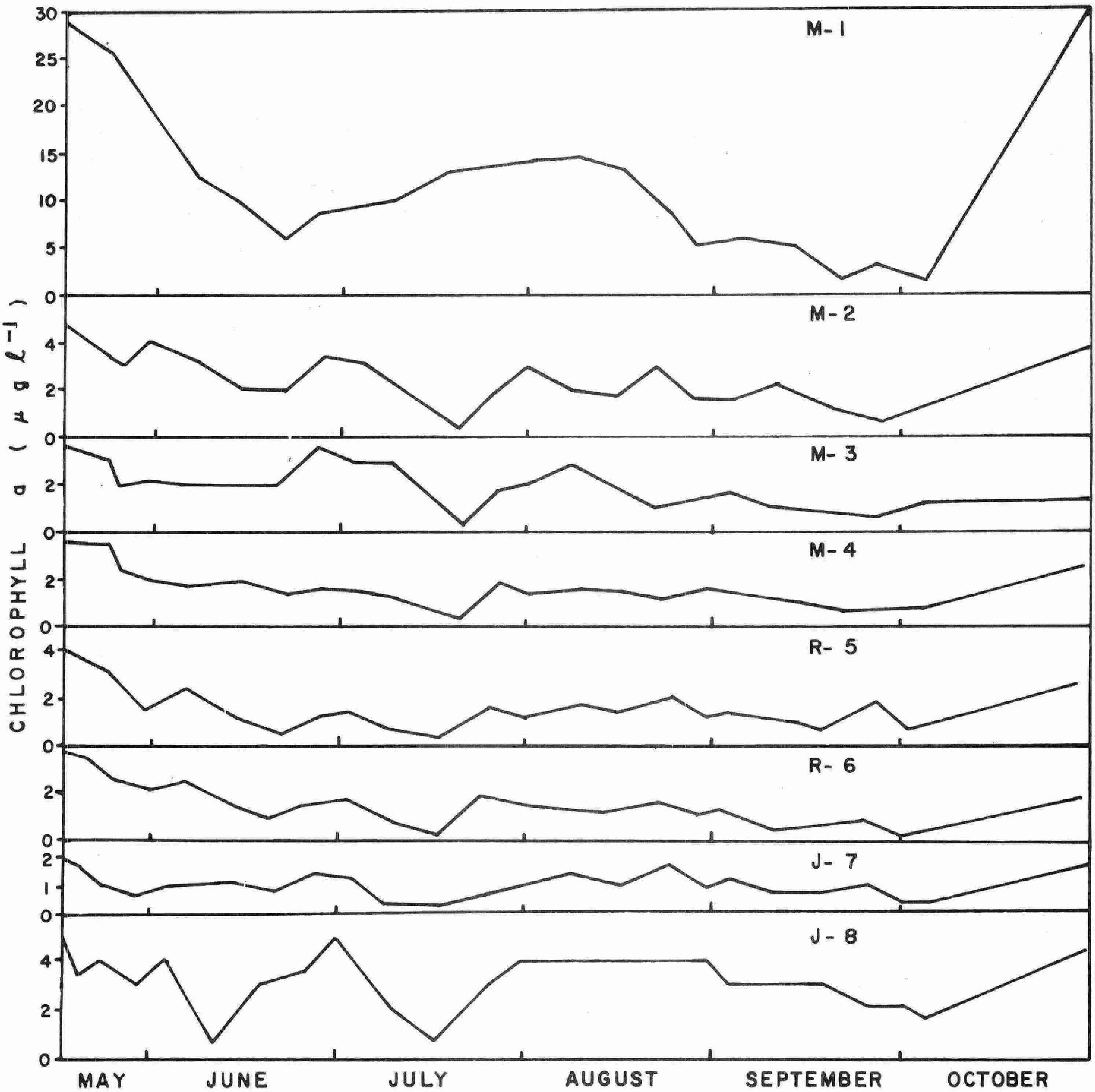

Fig. 22 Seasonal patterns of chlorophyll a in the euphotic zones of eight stations in the study area during the ice-free season of 1969.

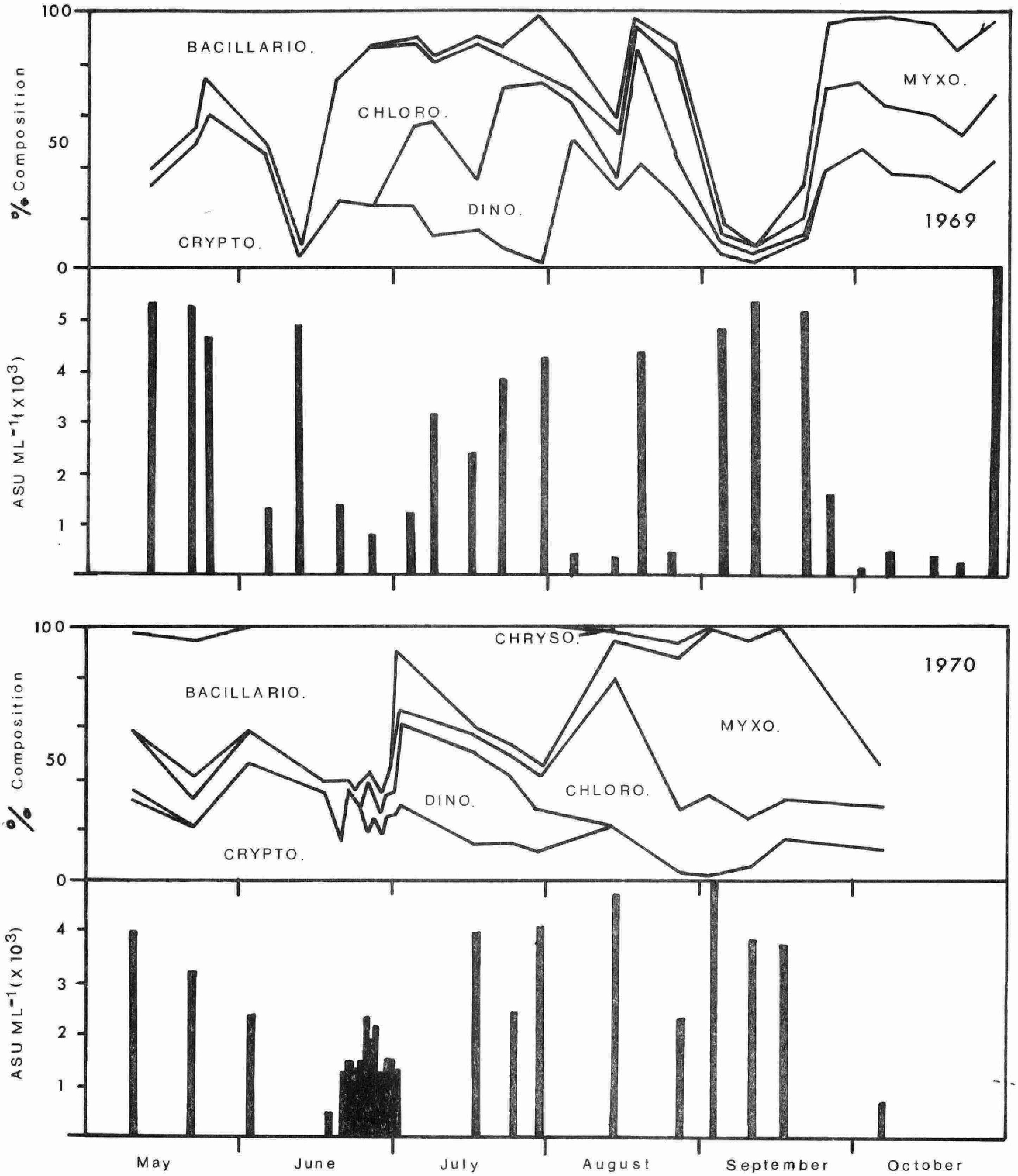

Figure 23: Phytoplankton stocks and composition in the euphotic zone at Station M-1 during the ice-free seasons of 1969 and 1970.

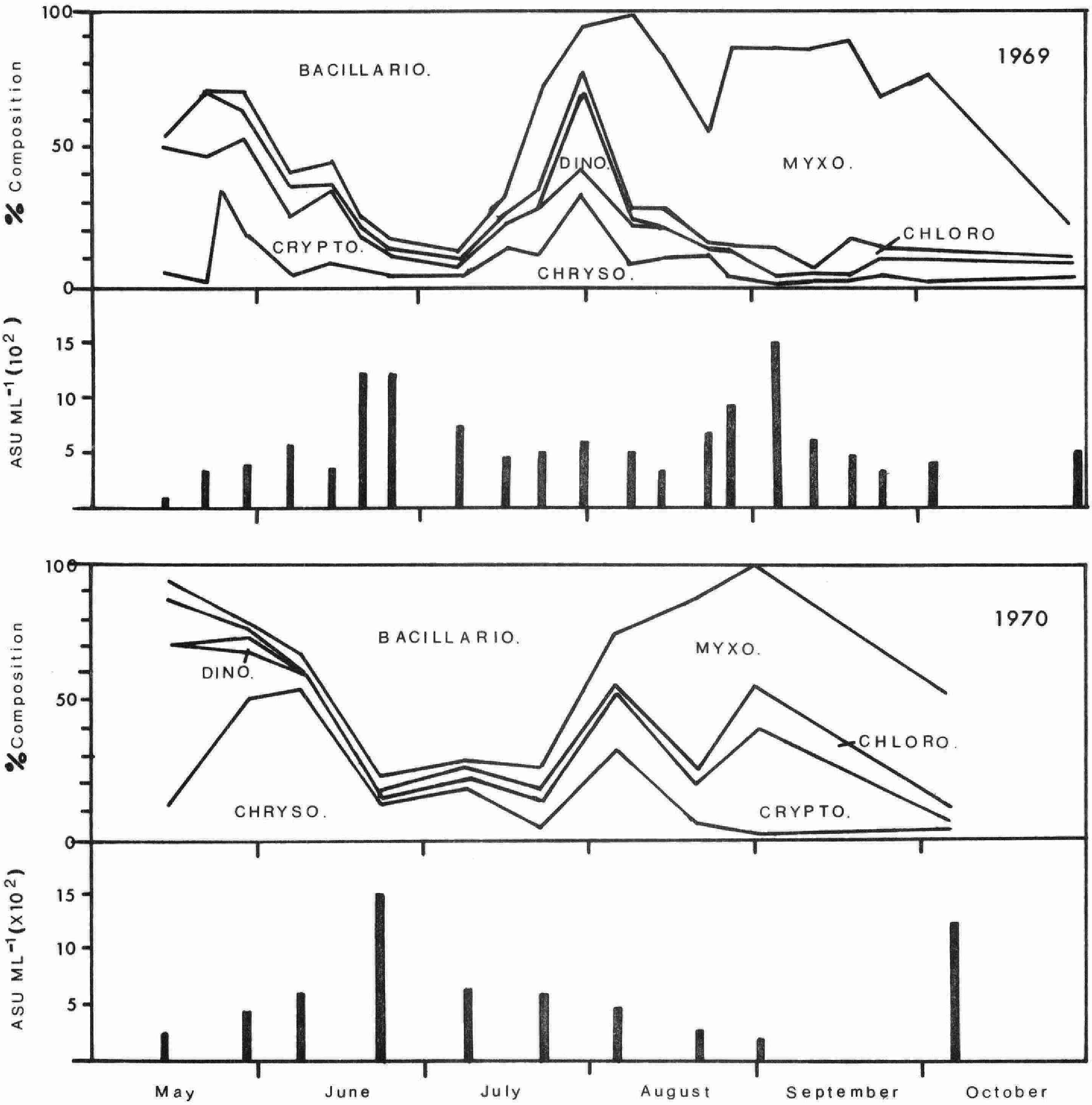

Figure 24: Phytoplankton stocks and composition in the euphotic zone at Station M-2 during the ice-free seasons of 1969 and 1970.

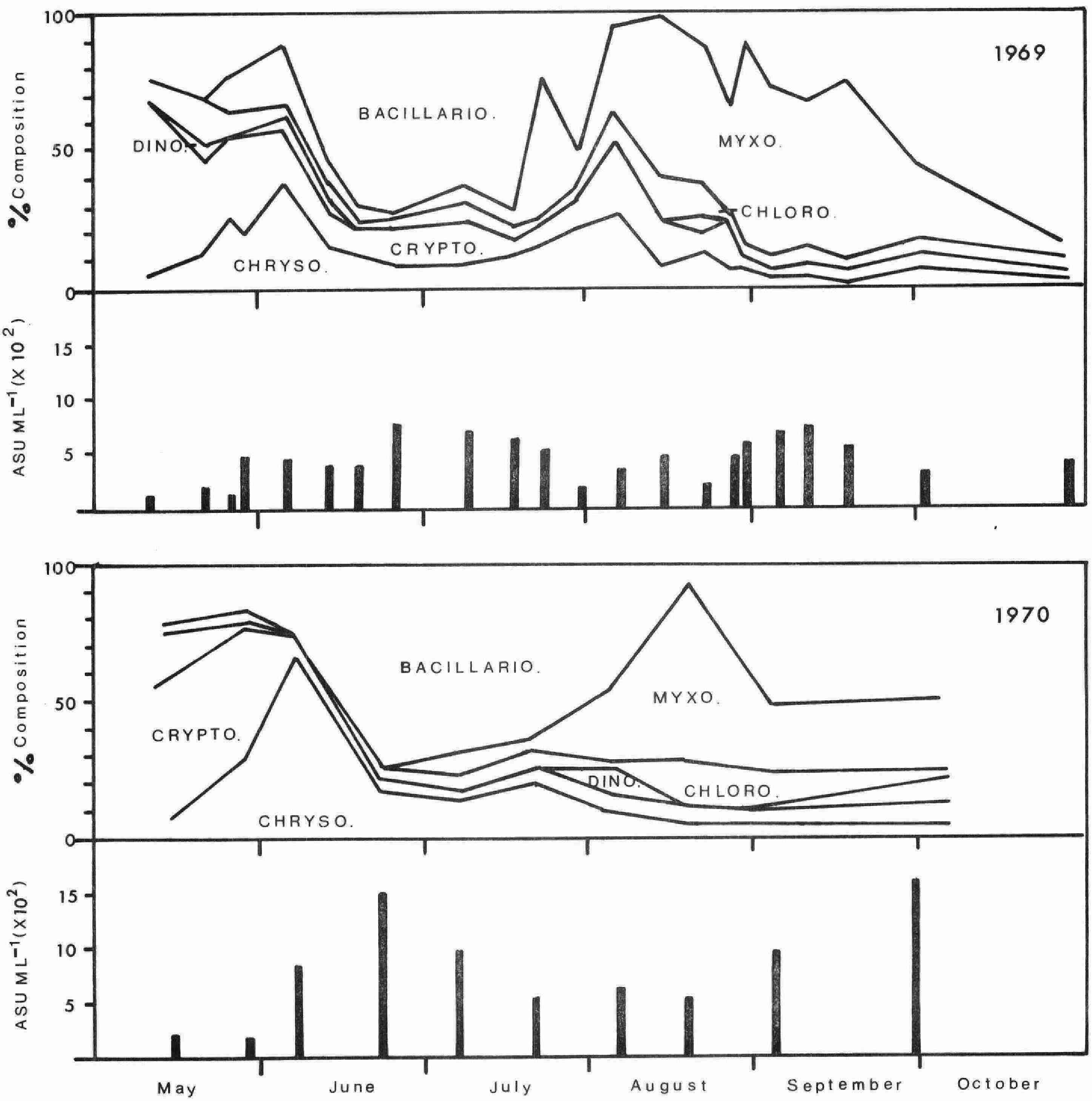

Figure 25: Phytoplankton stocks and composition in the euphotic zone at Station M-3 during the ice-free seasons of 1969 and 1970.

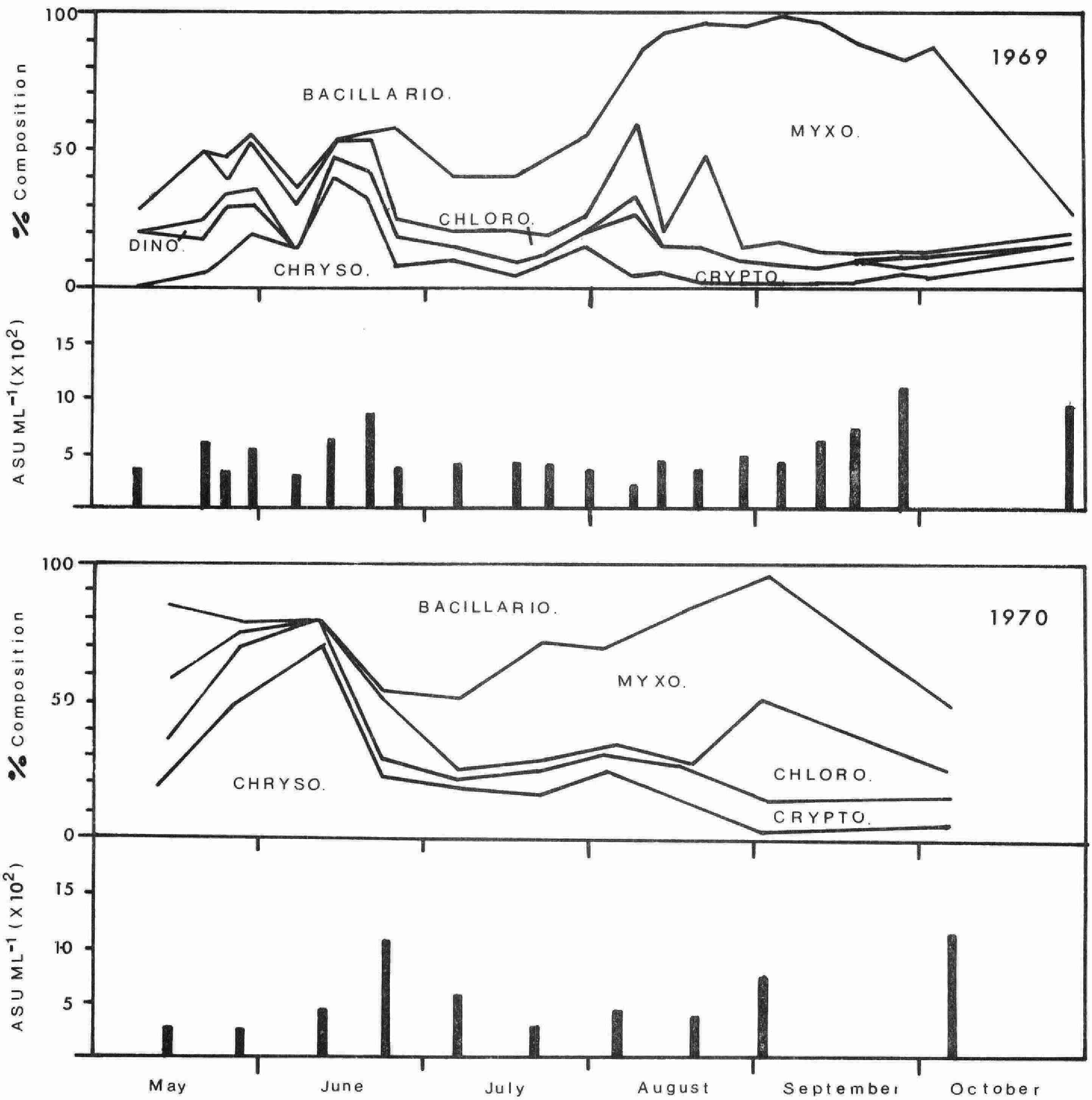

Figure 26: Phytoplankton stocks and composition in the euphotic zone at Station M-4 during the ice-free seasons of 1969 and 1970.

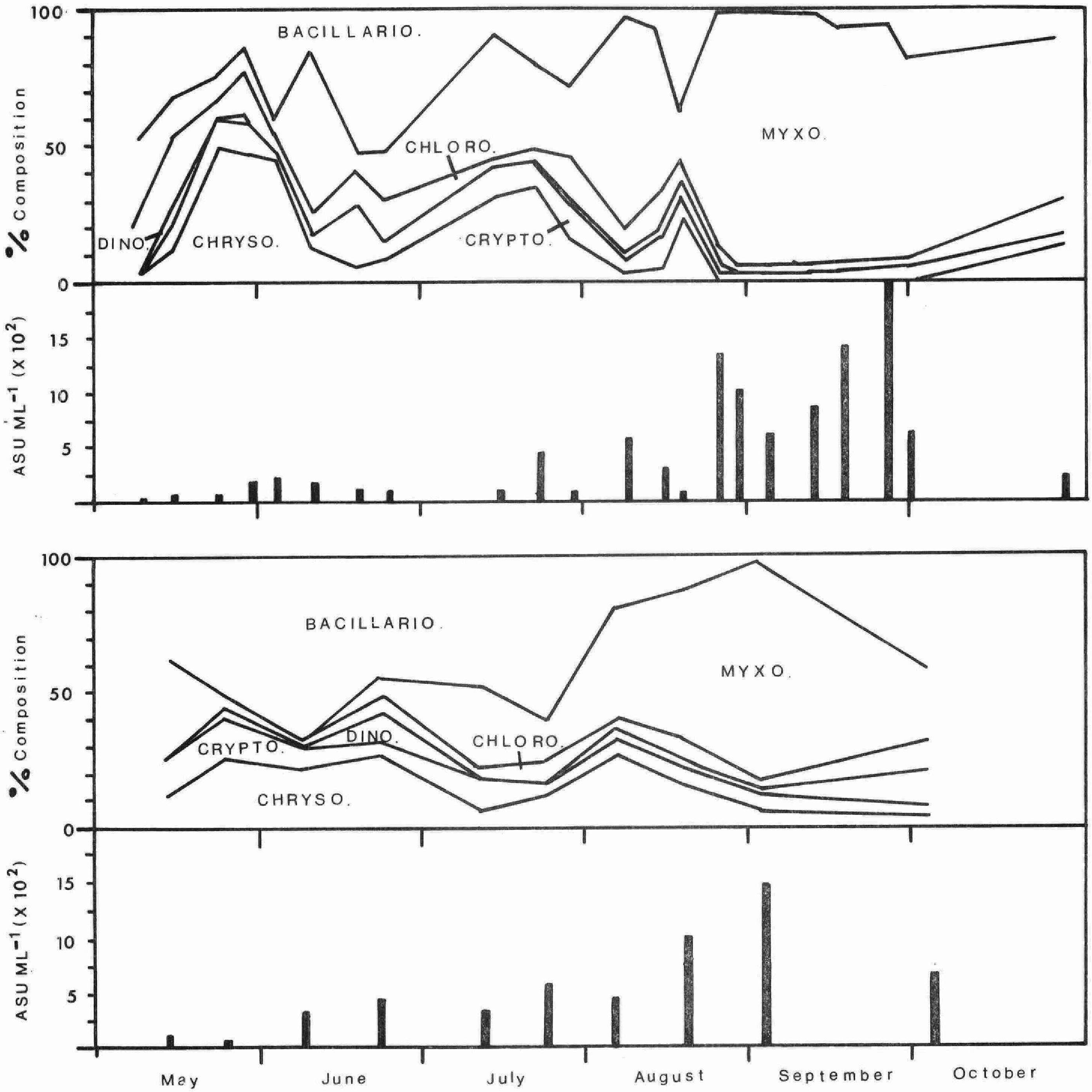

Figure 27: Phytoplankton stocks and composition in the euphotic zone at Station R-5 during the ice-free seasons of 1969 and 1970.

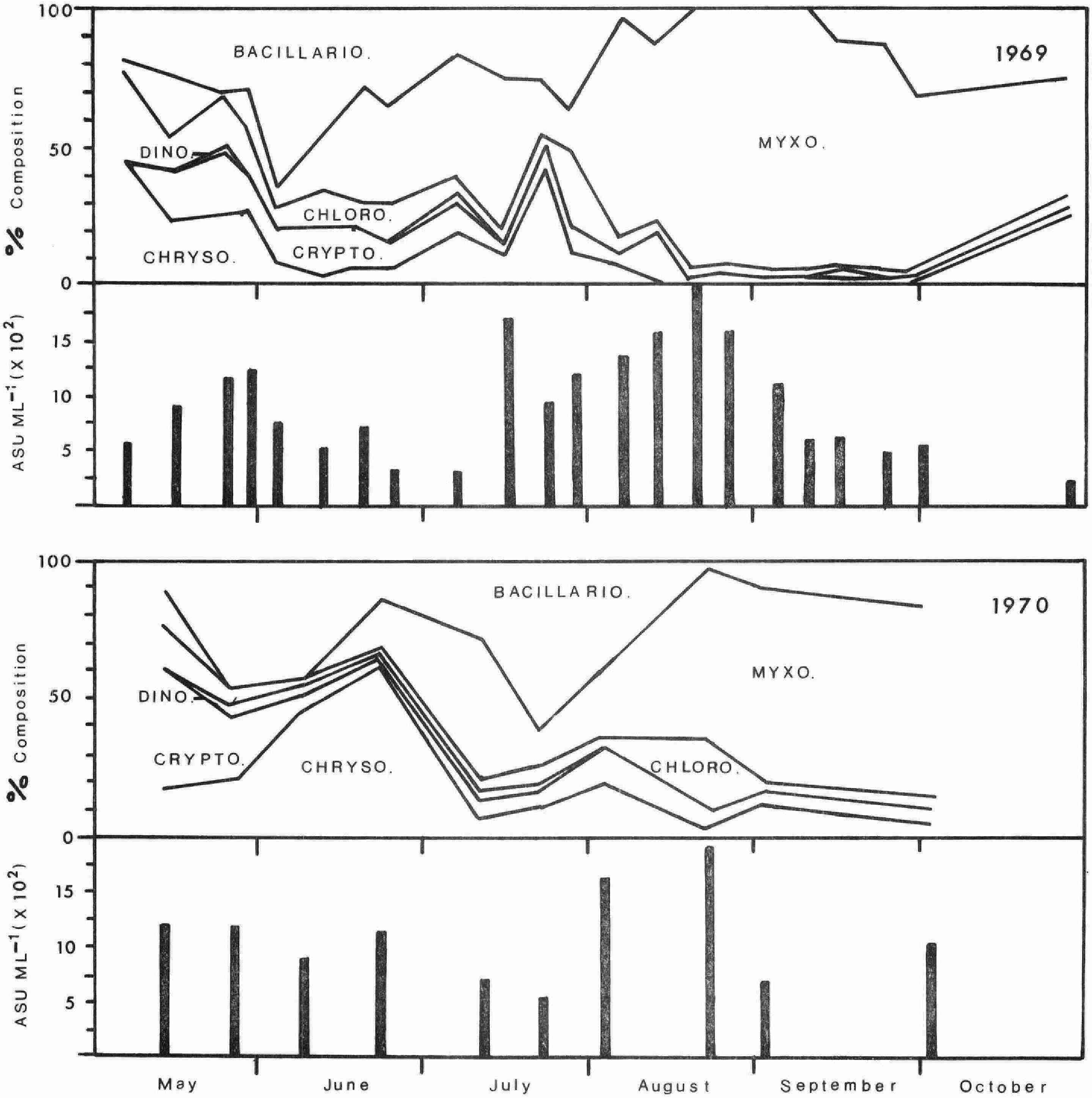

Figure 28: Phytoplankton stocks and composition in the euphotic zone at Station R-6 during the ice-free seasons of 1969 and 1970.

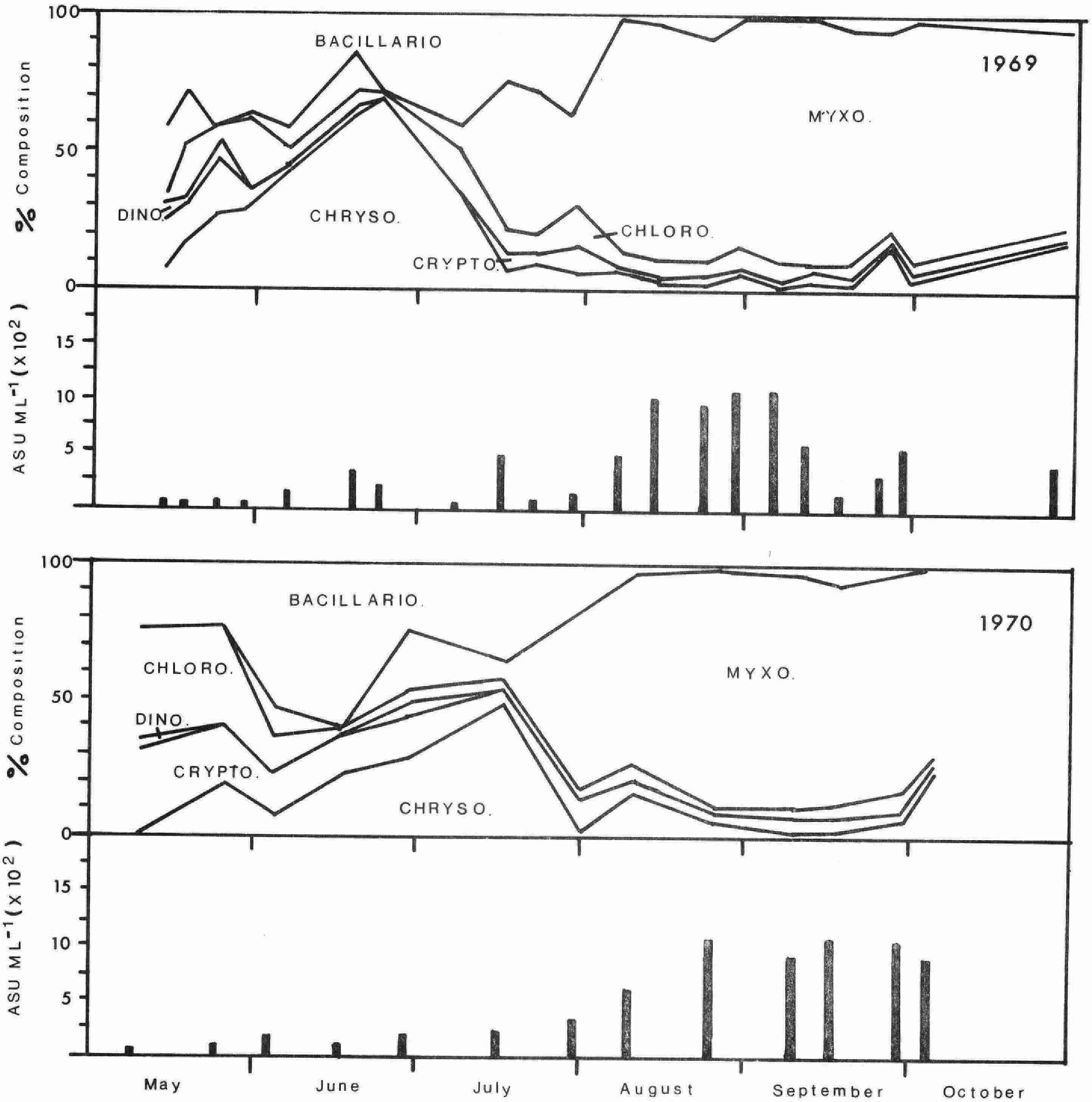

Figure 29: Phytoplankton stocks and composition in the euphotic zone at Station J-7 during the ice-free seasons of 1969 and 1970.

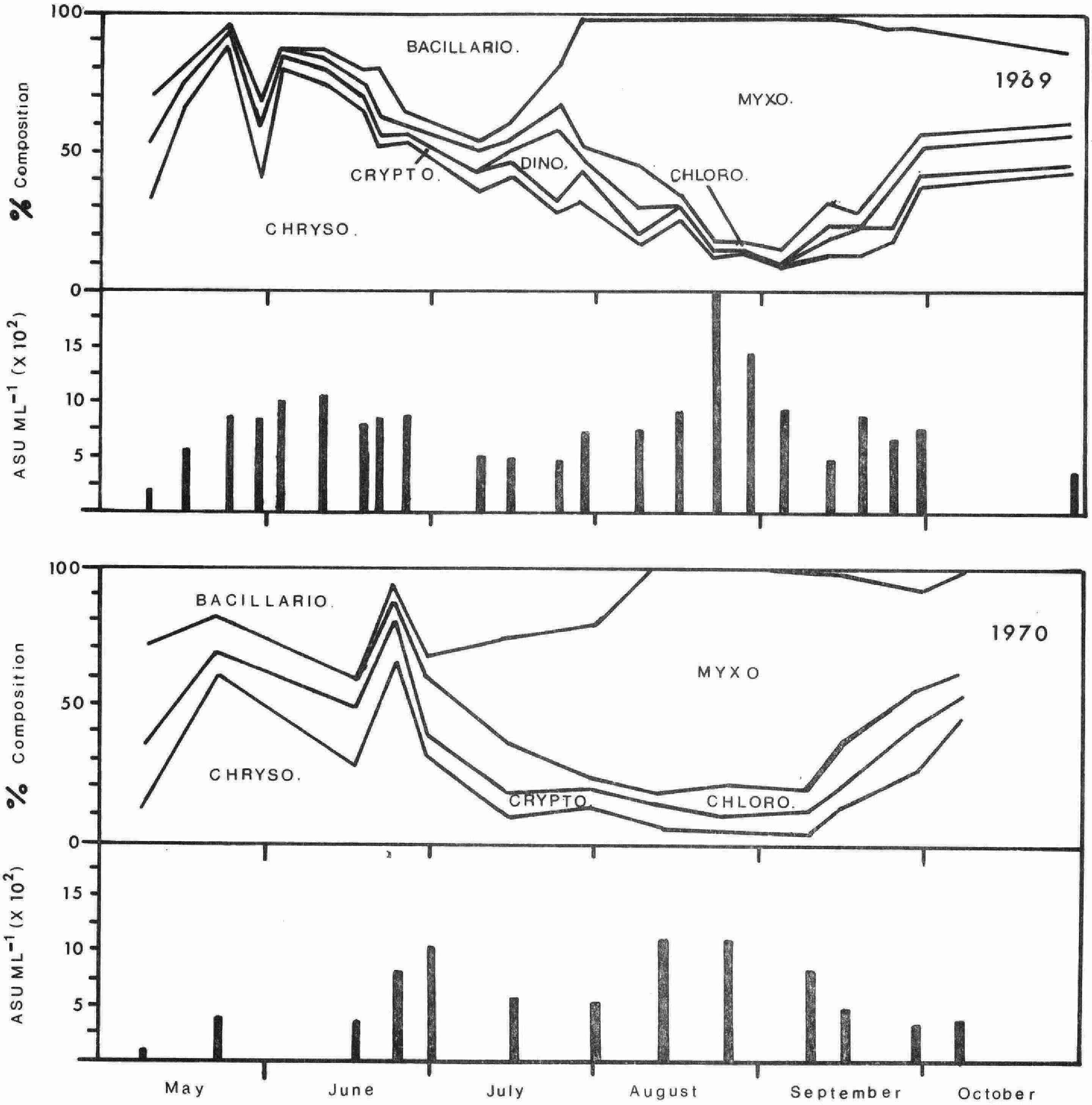

Figure 30: Phytoplankton stocks and composition in the euphotic zone at Station J-8 during the ice-free seasons of 1969 and 1970.

APPENDIX B

APPENDIX B

List of phytoplanktonic species encountered at eight sampling locations during the ice-free season of 1969 and 1970.

SPECIES	M1	M2	M3	M4	R5	R6	J7	J8
BACILLARIOPHYCEAE								
Achnanthes spp.	+	+	+	+	+	+	+	+
A. flexella var. *alpestris* Brun				+				
A. lanceolata (Breb.) Grun.	+		+	+		+		
A. microcephala (Kütz.) Grun.			+					
A. minutissima Kütz.					+	+		
Amphipleura sp.							+	
Amphora ovalis Kütz.					+			
Asterionella formosa Hassall	+	+	+	+	+	+	+	+
Ceratoneis arcus (Ehr.) Kütz.						+		
Cocconeis placentula Ehr.	+					+		+
Cyclotella bodanica Eulenstein	+		+		+	+	+	+
C. comta (Ehr.) Kütz.	+	+	+	+	+	+	+	+
C. michiginiana Skvortzow	+			+	+	+		+
C. ocellata Pant.			+	+	+	+	+	+
C. stelligera Cl. et Grun.	+	+	+	+	+	+	+	+
Cymbella spp.			+	+	+	+	+	
C. turgida (Greg.) Cleve						+		+
C. ventricosa Kütz.					+	+		+
Diatoma elongatum (Lyngb.) Ag.		+			+		+	
D. vulgare Bory					+			
Diploneis Smithii (Breb.) Cleve								+
Epithemia sp.								+
Eunotia spp.	+	+	+	+	+	+	+	+
E. elegans Østr.								+
E. pectinalis (Dillw. ? Kütz.) Rabh.			+	+	+	+		
E. rostellata Hust.							+	
E. tenella (Grun.) Hust.							+	
E. vanheurckii Patr.						+		
Fragilaria capucina Desm.		+			+			
F. crotonensis Kitton	+	+	+	+	+	+	+	+
F. intermedia Grun.	+	+	+					
Frustulia sp.			+	+	+			+

Appendix B - Continued..

SPECIES	M1	M2	M3	M4	R5	R6	J7	J8
Gomphonema spp.	+	+		+	+	+	+	+
G. acuminatum Ehr.				+			+	
G. angustatum (Kütz.) Rabh.					+			
Melosira ambigua (Grun.) O.Müll.	+	+	+	+	+	+	+	+
M. distans (Ehr.) Kütz.								+
M. granulata (Ehr.) Ralfs	+			+				
M. italica (Ehr.) Kütz.	+	+	+	+	+	+		+
Meridion circulare Ag.	+						+	+
Navicula spp.	+	+	+	+	+	+	+	+
N. cocconeiformis Greg.					+	+		
N. cryptocephala Kütz.	+		+			+		
N. elginensis var. lata (M. Perag.) Patr.					+			
N. protracta Grun.						+		
Nitzchia spp.	+	+	+	+	+	+	+	+
N. acicularis W.Smith	+	+	+	+				
N. acuta Hantzsch				+				
N. dissipata (Kütz.) Grun.		+	+			+		
N. fonticola Grun.								+
N. gracilis Hantzsch						+	+	
N. hungarica Grun.							+	
N. linearis W. Smith					+			
N. palea (Kütz.) W. Smith	+		+	+	+	+	+	+
N. recta Hantzsch				+	+		+	
N. sigmoidea (Ehr.) W. Smith					+			
N. vermicularis (Kütz.) Grun.						+		
Pinnularia biceps Greg.						+		
Rhizosolenia eriensis H.L. Smith	+	+	+	+	+	+	+	+
Stauroneis phoenicenteron Ehr.								+
Stephanodiscus astraea var. minutula (Kütz.) Grun.		+		+	+	+	+	+
S.invisitatus Hohn & Hellerman						+		
Surirella spp.			+	+	+	+	+	+
S. angustata Kütz.				+		+		+
Synedra sp.		+						
S. amphicephala Kütz.								+
S. famelica Kütz.					+			+
S. filiformis Grun.	+	+				+		
S. nana Meist.	+	+	+	+	+	+	+	+
S. rumpens Kütz.	+	+	+	+	+	+	+	+
S. tenere W. Smith	+	+	+	+	+	+	+	+
S. ulna (Nitzsch) Ehr.			+			+		+
Tabellaria fenestrata (Lyngb.) Kütz.	+	+	+	+	+	+	+	+
T. flocculosa (Roth) Kütz.	+	+	+	+	+	+	+	+

Appendix B - Continued

SPECIES	M1	M2	M3	M4	R5	R6	J7	J8
CHLOROPHYCEAE								
Actinastrum sp.								+
Ankistrodesmus falcatus (Corda) Ralfs	+	+	+	+	+	+	+	+
Arthrodesmus sp.	+		+	+	+	+	+	+
Botryococcus Braunii Kütz.	+		+	+	+		+	+
Characium limneticum Lemmermann	+	+	+		+	+	+	
Chlamydomonas spp.	+	+	+	+	+	+	+	+
C. epiphytica G.M. Smith	+	+	+	+	+	+	+	+
C. gloeophila Skuja		+	+	+	+			+
Chlorella vulgaris Beyerinck	+	+	+	+	+	+	+	+
Chlorococcum humicola (Naeg.) Rabh.	+							
Chlorogonium sp.	+	+						
Closteriopsis longissima Lemmermann	+					+		+
Closterium spp.	+		+	+	+	+	+	+
Closterium parvulum Naegeli				+	+	+		+
Coelastrum spp.	+	+	+	+	+	+	+	+
Coelastrum microporum Naegeli						+		
Cosmarium spp.	+	+	+	+	+	+	+	+
Crucigenia crucifera (Wolle) Collins		+						
C. fenestrata Schmidle						+		
C. quadrata Morren		+	+	+			+	
C. rectangularis (A.Braun) Gay		+	+	+	+	+	+	+
C. tetrapedia (Kirchner) W. & G.S. West		+	+	+	+	+	+	+
Dictyosphaerium sp.			+			+		
D. Ehrenbergianum Naegeli								+
D. pulchellum Wood	+					+	+	+
Elakatothrix sp.	+			+				
Euastrum sp.		+	+	+	+	+	+	+
Franceia sp.								+
Gloeocystis sp.	+	+		+	+	+	+	+
Golenkinia sp.			+				+	
Gonium sp.	+							
Kirchneriella sp.		+						

Appendix B - Continued

SPECIES	M1	M2	M3	M4	R5	R6	J7	J8
Micractinium sp.	+		+			+	+	+
Mougeotia sp.			+		+		+	
Nephrocytium lunatum W. West	+	+			+	+	+	+
Oocystis spp.	+	+	+	+	+	+	+	+
O. Borgei Snow							+	
O. parva W. & G.S. West							+	
Pediastrum spp.	+		+	+			+	+
P. duplex Meyen		+	+					
P. tetras (Ehr.) Ralfs			+					
P. tetras var. *tetraodon* (Corda) Rabh.						+		
Quadrigula Chodatii (Tan. - Ful.) G.M. Smith	+	+	+	+	+	+	+	+
Q. closterioides (Bohlin)Printz		+						
Q. lacustris (Chodat) G.M. Smith				+				
Scenedesmus spp.	+	+	+	+	+	+	+	+
S. acutiformis Schroeder			+	+				
S. bijuga (Turpin) Lagerheim			+					
S. obliquus (Turpin) Kütz.		+	+	+	+	+	+	+
S. quadricauda (Turpin) Brebisson			+			+		
Schroederia setigera (Schroeder) Lemm.	+	+	+	+	+	+	+	+
Selenastrum sp.		+		+	+	+	+	+
Sphaerocystis Schroeteri Chodat	+	+	+	+	+	+	+	+
Sphaerozosma sp.					+			
Spondylosium sp.	+			+	+		+	+
Staurastrum spp.	+	+	+	+	+	+	+	+
Stigeoclonium sp.	+							
Tetraëdron spp.		+	+	+		+	+	+
T. lunula (Reinsch) Wille			+	+	+			
T. minimum (A. Brown) Hansgirg		+	+	+	+	+	+	
Ulothrix sp.		+	+	+	+	+	+	+
Xanthidium subhastiferum West et G.S.West	+							

APPENDIX B - Continued

SPECIES	M1	M2	M3	M4	R5	R6	J7	J8
CHRYSOPHYCEAE								
Chrysosphaerella longispina Lauterborn	+	+	+	+	+	+	+	+
Dinobryon bavaricum Imhof	+	+	+	+	+	+	+	+
D. cylindricum Imhof	+	+	+	+	+	+	+	+
D. divergens Imhof			+	+			+	+
D. sertularia Ehr.	+	+	+	+	+	+	+	+
D. sociale Ehr.		+	+	+	+			+
D. Stokesii Lemmermann		+	+		+			
D. Vanhoeffenii (Krief.) Bachmann		+	+	+	+	+	+	+
Mallomonas spp	+	+	+	+	+	+	+	+
Ochromonas sp.	+			+	+	+	+	+
Rhizochrysis limnetica G.M. Smith		+						
Stipitococcus urcelolatus W. & G.S. West		+	+	+		+	+	+
Synura uvella Ehr.	+	+	+	+	+	+	+	+
CRYPTOPHYCEAE								
Cryptomonas spp.	+	+	+	+	+	+	+	+
C. erosa Ehr.	+	+	+	+	+	+	+	+
Rhodomonas minuta Skuja	+	+	+	+	+	+	+	+
DINOPHYCEAE								
Ceratium hirundinella (O. Müll.) Dujardin	+	+	+	+	+	+	+	+
Glenodinium sp.							+	+
Gymnodinium sp.	+		+			+		
Peridinium spp.	+	+	+	+	+	+	+	+
P. limbatum (Stokes) Lemmermann								+
P. pusillum (Penard) Lemmermann						+		
P. Willei Huitfeld - Kaas					+			
EUGLENOPHYCEAE								
Euglena sp.				+		+	+	+
Lepocinclis sp.	+		+	+			+	+
Phacus sp.	+		+			+	+	
Trachelomonas spp.	+	+	+	+	+	+	+	+

	M1	M2	M3	M4	R5	R6	J7	J8
MYXOPHYCEAE								
Anabaena spp.	+	+	+	+	+	+	+	+
Anabaena flos-aquae (Lyngb.) De Brebisson	+							
Aphanizomenon flos-aquae (L.)Ralfs	+	+	+	+	+	+		
Aphanocapsa sp.	+	+	+	+	+	+	+	+
A. elachista West & West		+			+			
Aphanothece sp.	+	+			+		+	
A. clathrata W. & G.S. West		+	+	+			+	+
A. gelatinosa (Henn.) Lemmermann		+	+	+	+	+	+	+
A. microscopica Naegeli			+			+		
A. nidulans P.Richter		+	+	+		+	+	+
A. saxicola Naegeli		+		+	+	+	+	+
Chroococcus spp.	+	+	+	+	+	+	+	+
C. dispersus (Keissler) Lemmermann								+
C. limneticus Lemmermann	+	+	+	+	+	+	+	+
C. Prescottii Drouet & Daily							+	
Coelosphaerium Naegelianum Unger	+	+	+	+	+	+		
Dactylococcopsis sp.	+	+	+	+	+	+	+	+
D. acicularis Lemmermann		+						
D. Smithii Chodat & Chodat		+						
Gloeocapsa sp.		+		+				
Gomphosphaeria spp.	+	+	+	+		+	+	+
G. aponina Kütz.		+	+		+	+	+	+
G. lacustris Chodat		+	+	+	+	+	+	+
Lyngbya spp.	+		+	+	+	+	+	+
L. limnetica Lemmermann			+		+	+	+	+
Merismopedia spp.		+	+	+	+	+	+	+
M. elegans A. Brown		+	+	+	+		+	+
M. tenuissima Lemmermann		+	+	+	+	+	+	+
Microcystis aeruginosa Kütz.	+	+	+	+	+	+	+	+
Oscillatoria spp.	+	+	+	+	+	+	+	
Pelogloea bacillifere Lauterborn						+		
Phormidium sp.						+		
P. mucicola Naumann & Huber-Pestalozzi					+			
Plectonema sp.					+	+	+	+
Rhabdoderma lineare Schmidle & Lauterborn	+	+	+	+	+	+	+	+
Spirulina sp.			+		+	+		

APPENDIX C

APPENDIX C

Table 1: Crustacean abundance (in number of individuals l^{-1}) in Gravenhurst Bay from May 23 to September 24, 1969.

Date	Depth	Nauplius larvae	Diaptomus minutus	Diaptomus oregonensis	Cyclops biscuspidatus thomasi	Mesocyclops edax	Polyphemus pediculus	Diaphanosoma leuchtenbergianum	Daphnia sp.	Daphnia ambigua	Daphnia longiremis	Daphnia retrocurva	Daphnia galeata mendotae	Bosmina sp.
May 23	Surface	20.7	2.4		18.5				3.4					0.2
	3.5m	253.0			94.0	4.3			7.2					2.9
	7.0m	7.2			15.9									
	10.5m	2.4			2.6									
	14.0m	7.4			5.7	2.4								0.2
June 6	Surface	10.1			120.0	1.4							11.5	64.9
	4.0m	34.6	2.8		289.1	4.3		5.7					30.3	17.3
	8.0m				66.5								1.4	4.3
	10.0m	7.2			52.0									7.2
	14.0m	1.4			44.8									4.3
June 19	Surface	52.5	1.2		31.3								102.6	38.7
	4.0m	57.8		1.4	86.7								102.6	36.1
	8.0m	18.7			116.1	4.3							21.6	10.1
	10.0m	14.4			79.5								21.6	2.8
	14.0m	17.3			96.8	1.4						0.4	7.9	0.2
July 16	Surface	4.3	1.4			39.0		1.4					2.8	1.4
	4.0m	5.7			11.5	11.5							31.8	5.7
	8.0m	13.0			10.1	5.7							7.2	2.8
	10.m	4.3			2.8	2.8			5.7					2.8
	14.0m	11.5			28.6	5.9							2.8	

Table 1 - Continued.....

Date	Depth	Nauplius larvae	Diaptomus minutus	Diaptomus oregonensis	Cyclops biscuspidatus thomasii	Mesocyclops edax	Polyphemus pediculus	Diaphanosoma leuchtenbergianum	Daphnia sp.	Daphnia ambigua	Daphnia longiremis	Daphnia retrocurva	Daphnia galeata mendotae	Bosmina sp.
July 30	Surface	16.8	0.2		0.7	5.9			2.5					20.3
	4.0m	6.9	0.5		0.2	24.3		1.2	4.8				0.5	8.9
	8.0m	9.8			2.3	0.5			2.8	0.5	0.7			4.1
	10.0m	4.4			1.0	0.5			8.8	2.5				0.7
	14.0m	9.3	0.2		5.1	0.5			9.6					
Aug. 13	Surface	46.8	0.5			4.6		0.5	1.0					66.5
	4.0m	32.3		1.8	0.7	22.0		9.0					0.7	155.4
	8.0m	2.5			1.2	1.0		0.5	2.5		0.5			6.4
	10.0m	7.2		0.7	0.5	0.2			1.5		2.3			2.8
	14.0m	14.2		0.5	1.2	1.5			3.1	0.7	0.2			1.0
Aug. 26	Surface	16.3	0.2			0.7		1.0	0.5					9.0
	4.0m	10.8		1.2		4.9		3.6					0.7	50.0
	8.0m	2.5			2.5				2.8		0.5			4.6
	10.0m	2.5			0.5	0.2			1.8		0.5			4.1
	14.0m	0.7			0.2			0.5	0.5				0.2	0.7
Sept. 10	Surface	1.0			0.5	1.0		1.2	2.5			0.9		2.5
	4.0m	0.5		1.0		3.1		1.2	14.7				1.8	5.6
	8.0m	1.5		0.5	1.5	1.5		0.7	3.3	0.2		1.2	1.0	5.9
	10.0m	3.3		0.7	2.8				3.5		1.8			0.5
	14.0m	1.2		0.5	2.0			0.5	1.2	0.7	0.2			0.2
Sept. 24	Surface	7.7		2.3	0.5	2.5	0.2	3.1	3.8					5.9
	4.0m	12.1		3.1	1.0	1.0		4.9	10.8				2.3	8.0
	8.0m	3.3		0.5		1.0		1.5	5.9					4.4
	10.0m	17.6		0.7	2.5	0.2		0.2	6.4		1.0			0.2
	14.0m	0.2			0.5				0.5					0.2

APPENDIX C

Table 2: Crustacean abundance (in number of organisms l^{-1}) in Little Lake Joseph from June 3 to September 9,1969.

Date	Depth	Nauplius larvae	Senecella calanoides	Epischura lacustris	Diaptomus minutus	Diaptomus oregonensis	Cyclops biscuspidatus thomasi	Mesocyclops edax	Cyclops scutifer	Polyphemus pediculus	Sida crystallina	Holopedium gibberum	Diaphanosoma leuchtenbergianum	Daphnia sp	Daphnia longiremis	Daphnia retrocurva	Daphnia galeata mendotae	Bosmina sp.
June 3	Surface	14.6			8.4		7.2	1.2				0.7		1.4	0.7			2.1
	8.0m	46.7			13.2		12.0	8.4						2.8	1.4			4.3
	18.0m	1.6			0.2		0.2											
	26.0m	2.1					0.5											
	34.0m	0.7			0.2													
June 17	Surface	8.6			2.4		2.4	0.5		0.2					1.2			3.3
	8.0m	24.0			13.0	1.9	17.5							0.7	15.6			1.2
	18.0m	7.9			0.2		4.5							0.2				0.4
	26.0m	1.0			0.7		1.4											0.7
	36.0m	7.2			3.6		7.2							0.2				1.4
July 1	Surface	14.4			3.6		1.4								1.0			1.6
	8.0m	11.3			12.9	0.5	12.5							0.2	14.4			0.7
	18.0m	26.5			1.9		1.4								0.2			1.9
	26.0m	6.5			1.4		1.2											0.7
	36.0m	9.8			1.6		2.1											0.2
July 15	Surface	1.4			0.5		1.4								0.5			0.5
	8.0m	6.2			4.0		10.5							0.9	5.3	0.2		1.2
	18.0m	34.6			2.6		1.6	0.2					0.2					
	26.0m	5.3			1.2		1.8							0.7	0.2		0.2	0.9
	36.0m	5.0	0.2	0.2	1.4		2.5	0.2			0.2			1.2			0.5	0.5

Table 2 - Continued.....

Date	Depth	Nauplius larvae	Senecella calanoides	Epischura lacustris	Diaptomus minutus	Diaptomus oregonensis	Cyclops biscuspidatus thomasi	Mesocyclops edax	Cyclops scutifer	Polyphemus pediculus	Sida crystallina	Holopedium gibberum	Diaphanosoma leuchtenbergianum	Daphnia sp.	Daphnia longiremis	Daphnia retrocurva	Daphnia galeata mendotae	Bosmina sp.
July 29	Surface	20.9			1.0			0.7					0.5	1.0				
	8.0m	6.7			5.1		8.7	0.5						6.7	4.4	0.2		1.8
	18.0m	75.9			2.5				1.2					0.2				0.7
	26.0m	23.8			1.5				2.3									0.2
	36.0m	18.6			2.5				3.1									0.2
Aug. 12	Surface	6.0			2.0		1.8	0.5						0.7	0.2			0.2
	8.0m	23.3			4.3		7.9	0.5									10.3	0.7
	18.0m	59.8			3.5		2.5											0.7
	26.0m	21.2			0.7		1.2											
	36.0m	19.4			0.7		1.2											0.2
Aug. 27	Surface	0.7			0.2		0.2											
	8.0m				12.0		22.4	1.2							5.7			0.7
	18.0m	66.2			2.8		3.3											0.2
	26.0m	21.9			0.7		3.1											
	36.0m	19.7			0.7		2.1											
Sept. 9	Surface	11.3			1.7			0.2							0.7			0.5
	8.0m	9.3			6.6		11.6	1.0					0.2	1.0	5.1			0.5
	18.0m	35.2			1.0		0.7											0.2
	26.0m	14.2					0.2	0.2										
	36.0m	36.7			1.8		2.3								0.5			0.2

APPENDIX C

Table 3: Crustacean abundance (in number of individuals l^{-1}) in Lake Joseph May 22 to September 9, 1969.

Date	Depth	Nauplius larvae	Senecella calanoides	Epischura lacustris	Diaptomus minutus	Diaptomus sicilis	Diaptomus oregonensis	Cyclops bicuspidatus thomasi	Mesocyclops edax	Polyphemus pediculus	Sida crystallina	Holopedium gibberum	Diaphanosoma leuchtenbergianum	Daphnia sp.	Daphnia longiremis	Daphnia catawba	Daphnia galeata mendotae	Bosmina sp.
May 22	Surface	28.4				0.2		3.3										
	15.0m	18.5	0.2			2.4		1.9										
	30.0m	7.4				0.4		3.1										
	45.0m	9.1						4.3										0.2
	60.0m	7.2				0.2	0.4	4.0										0.4
June 4	Surface	49.3			7.2			5.5							0.4			1.2
	16.0m	10.8			2.1	1.2		1.6										
	32.0m	2.6			0.4													0.2
	48.0m	1.0	0.2		0.7			0.4										
	64.0m	4.0			1.0			1.2										0.2
June 17	Surface	22.4		0.2	14.2			2.8				0.7						1.6
	16.0m	25.5	1.0		2.4	2.4	19.5	3.1	0.4			0.4						
	32.0m	24.0		0.2	17.5	1.2		1.2	1.2	0.4		1.6		0.2				2.6
	48.0m	3.8			0.2	0.2		0.2										0.2
	64.0m				0.4			1.0							0.4			
July 2	Surface	10.8			2.1			0.2						0.2				0.7
	16.0m	7.2	0.2		9.8	0.2		1.4				0.4						3.5
	32.0m	6.7	0.4		1.2			0.4										
	48.0m	8.1	0.2		0.4			0.4										0.2
	64.0m	3.6			0.2			0.6		0.2								0.7

Table 3 - Continued

Date	Depth	Nauplius larvae	Senecella calanoides	Epischura lacustris	Diaptomus minutus	Diaptomus sicilis	Diaptomus oregonensis	Cyclops bicuspidatus thomasi	Mesocyclops edax	Polyphemus pediculus	Sida crystallina	Holopedium gibberum	Diaphanosoma leuchtenbergianum	Daphnia sp.	Daphnia longiremis	Daphnia catawba	Daphnia galeata mendotae	Bosmina sp.
July 15	Surface	1.2			1.4													0.2
	16.0m	12.7	0.4		20.4		4.8	1.2	0.2					0.4				1.2
	32.0m	11.5		0.2	0.7		1.2	1.2				0.2		0.4				
	48.0m	20.7	0.2		4.0				1.6	0.2	0.2			0.2				0.4
	64.0m	1.3		0.4	1.6			0.7	7.9	1.9	15.6	0.2		4.0		0.4		2.4
July 29	Surface	5.9			4.1			1.0	0.2									0.4
	16.0m	9.0			29.7	0.7		0.5			0.2				0.7			1.5
	32.0m	17.3			5.4													
	48.0m	12.9			2.5													
	64.0m	14.2	0.5	0.2	3.8			1.0						0.2				0.5
Aug. 12	Surface	5.1			4.4			0.5	0.2						0.5			
	16.0m	9.0			17.0										0.2			0.5
	32.0m	22.7			3.3													
	48.0m	17.0		3.6														
	64.0m	12.9	0.2		1.8			0.2										0.2
Aug 27	Surface	9.8			2.3			0.5			0.2							
	16.0m	13.9			14.2			1.2							0.2		0.5	
	32.0m	9.0			2.3			0.2										0.2
	48.0m	6.7			0.5			0.7										0.5
	64.0m	10.1			1.2						0.2							1.5
Sept 9	Surface	5.4			5.6			1.0					0.2	0.2				0.5
	16.0m	9.0			11.1			0.5	0.5						0.5			0.2
	32.0m	7.7	0.2		2.3			0.2										
	48.0m	10.3			0.2													
	64.0m	3.8			0.5			0.5	0.2									